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The Neutron Lifetime Experiment at LANL

Steven Clayton for the UCNT collaboration

S. Clayton, M. Makela, C. Morris, J. Ramsey, A. Saunders, S. Seestrom, P. Walstrom, Z. Wang (LANL)

D. Bowman, S. Penttila (ORNL)

E. Adamek, C. Cude, W. Fox, A. Holley, M. Hozo, C.-Y. Liu, N. Callahan, D. Salvat, J. Vanderwerp, B. Slaughter, K. Solberg, M. Snow (Indiana U.)

B. Vogelaar (V. Tech)

K. Hickerson (UCLA)

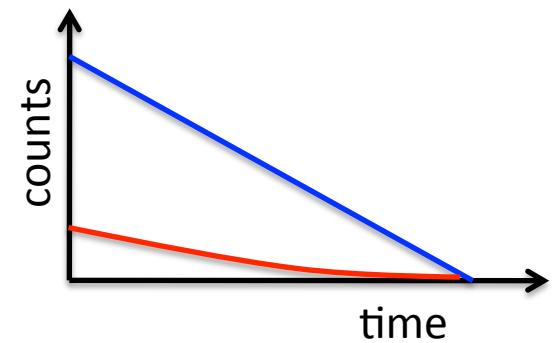
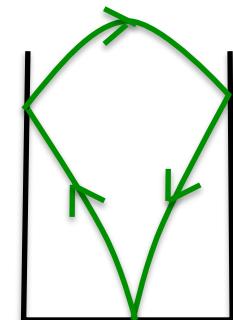
A. R. Young, B. VornDick, E. Dees (NCSU)

Overview

- Neutron lifetime
 - Fundamental property of n
 - Important input governing BBN
 - Key input for weak universality tests
 - Cleanest extraction of V_{ud}
 - Current discrepancy in experiments
- New neutron lifetime experiment using UCN
 - UCN from LANL Solid D₂ source
 - Asymmetric magneto-gravitational trap
 - Prototype was constructed using LANL LDRD funds
 - First storage time tests were done this year

Possible sources of systematic errors

- Finite τ_{loss} in $N = N_0 \exp(-t/\tau_n - t/\tau_{\text{loss}})$
 - Interaction with matter
 - **Quasi-trapped orbits**
- Time-dependent detection bias
 - Phase space evolution + efficiency variation
 - Long draining time
- Time-dependent **background**
- Other...



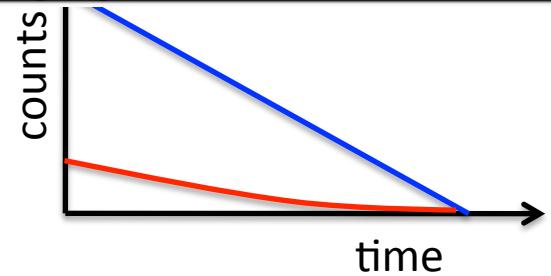
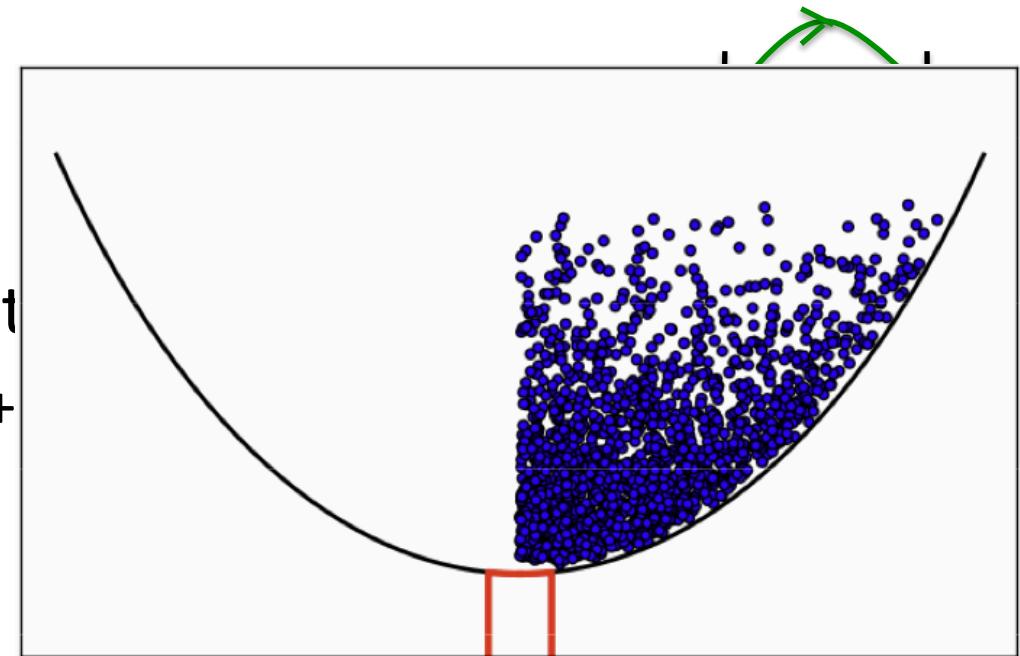
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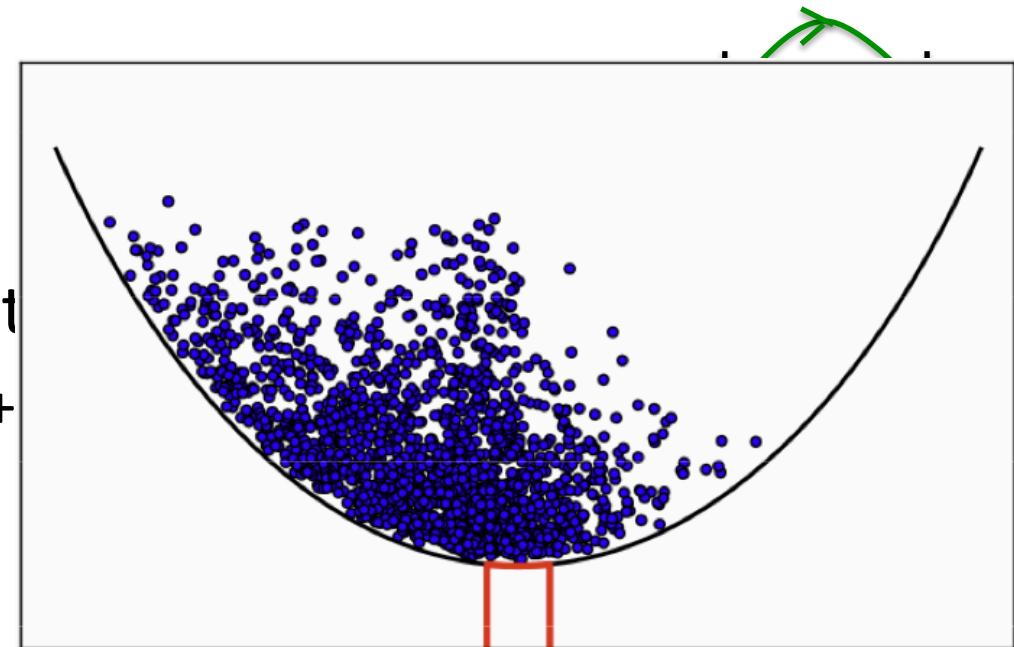
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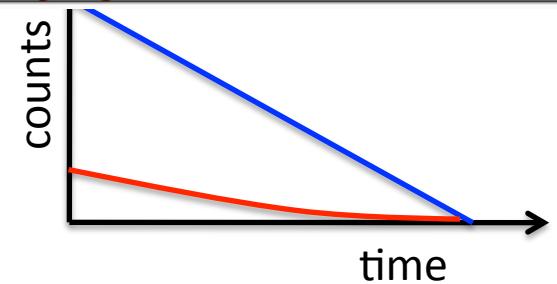


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- Other...



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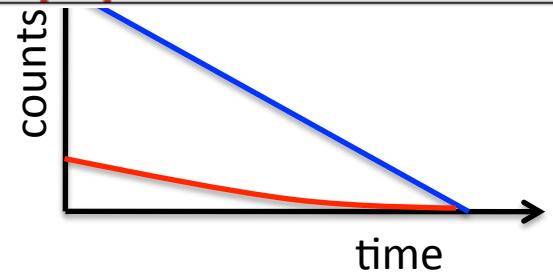
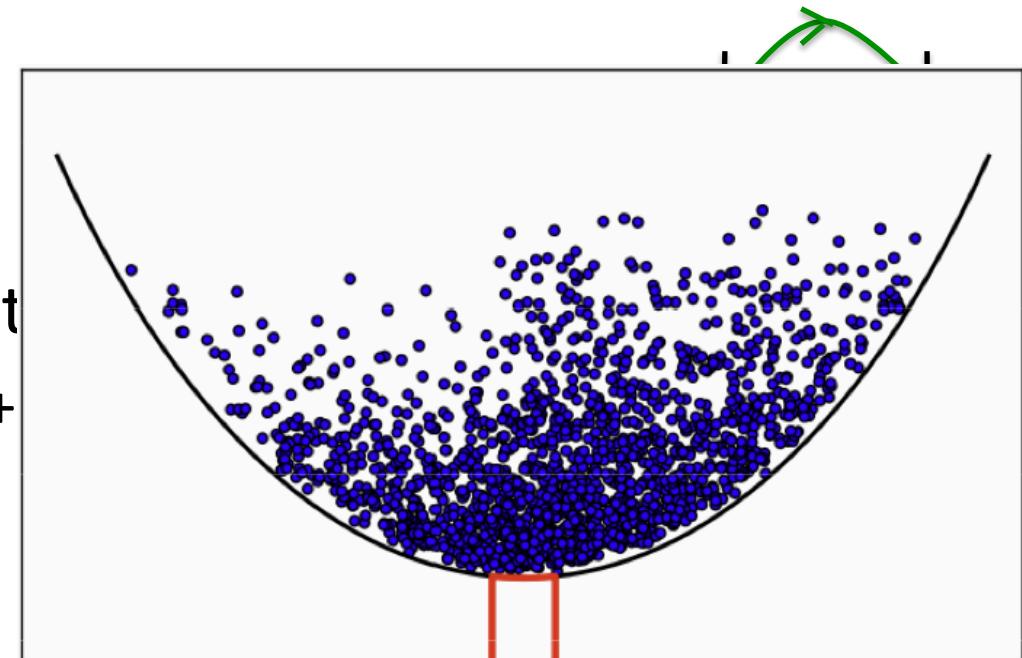
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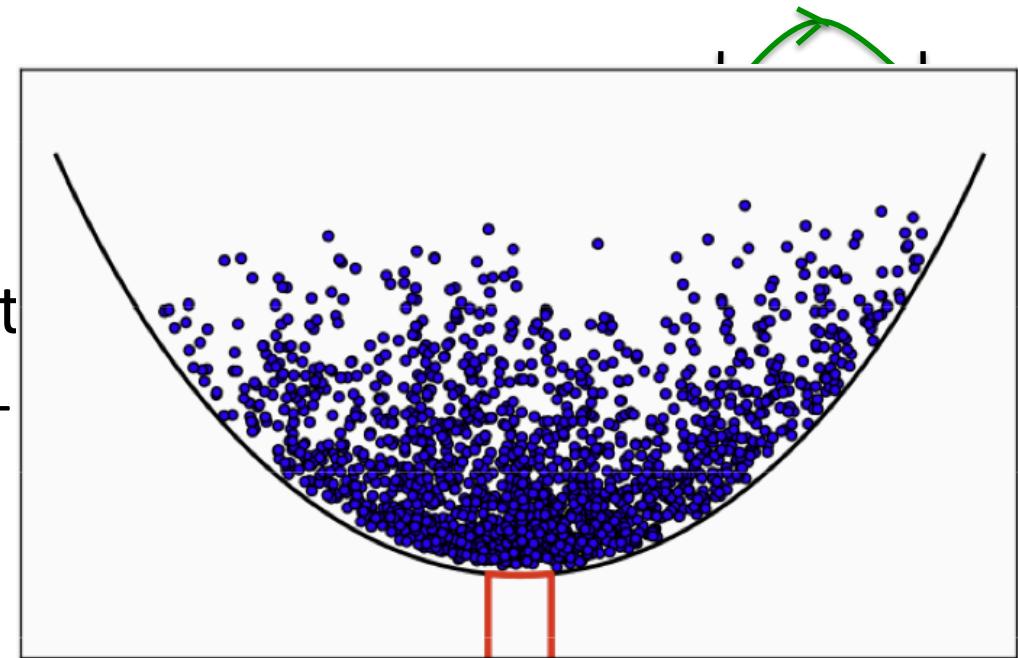
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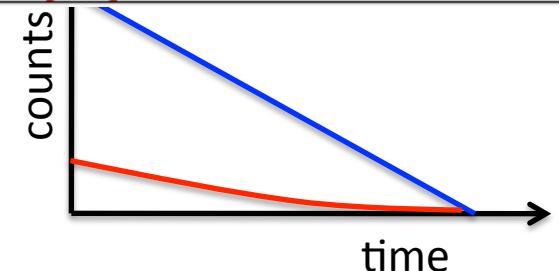
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- Time-dependent detection

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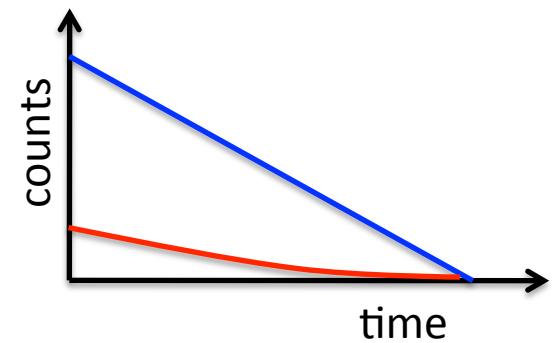
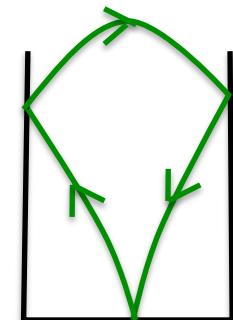
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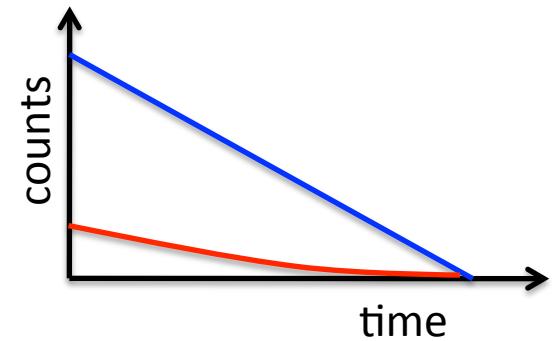
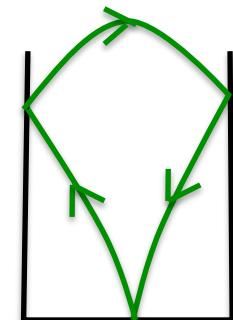
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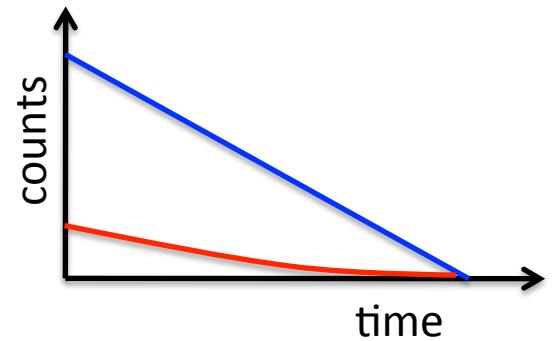
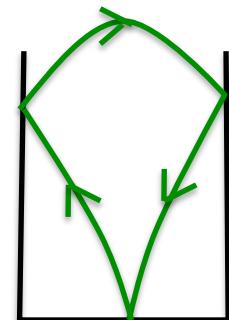
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- Finite τ_{loss} in $N = N_0 \exp(-t/\tau_n - t/\tau_{\text{loss}})$
 - ~~Interaction with matter~~ → Magneto-gravitational trap with holding field
 - ~~Quasi-trapped orbits~~ → Asymmetric trap with ripple for fast cleaning
- Time-dependent detection bias
 - Phase space evolution + efficiency variation
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- Other...



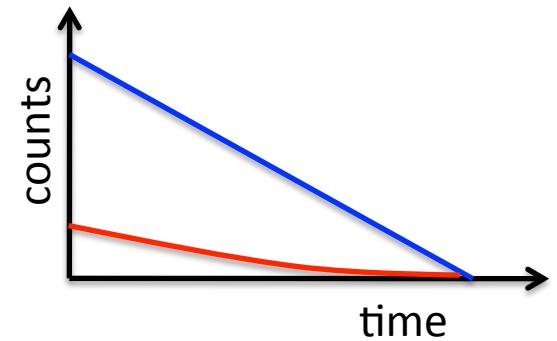
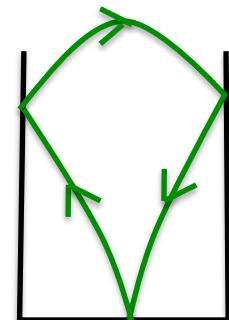
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- Other...



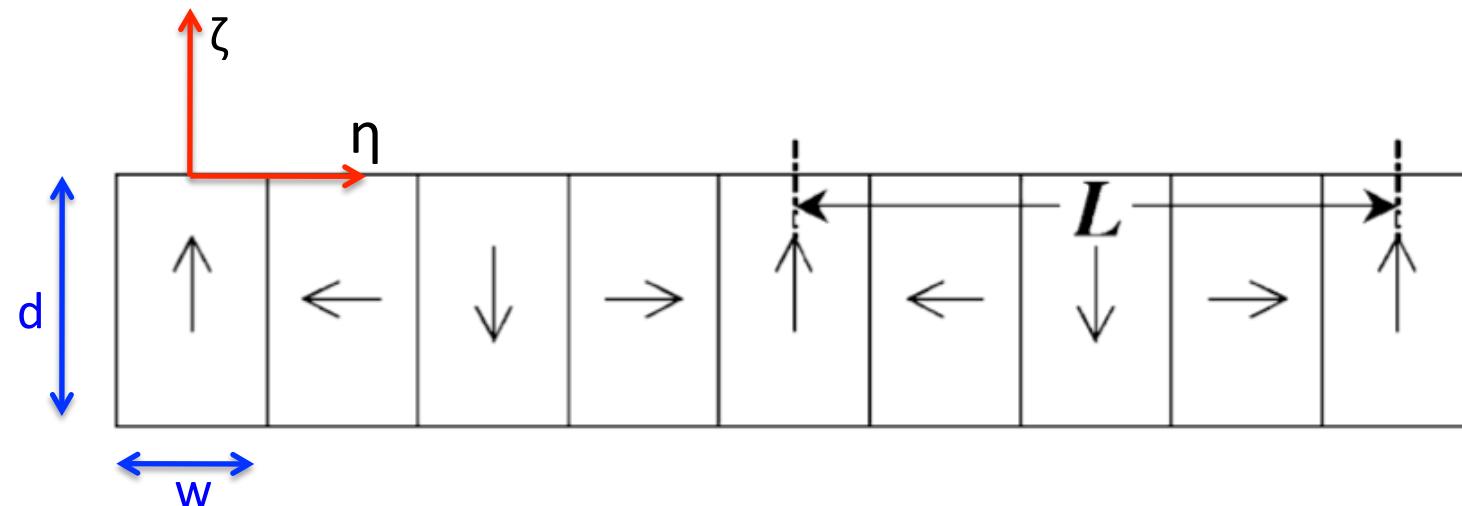
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 - ~~Phase space evolution + efficiency variation ?~~
 - ~~Long draining time~~ → Asymmetric trap, *in situ* n detection
- ~~Time dependent background~~
→ Some options...
- Other...



No material interactions: Halbach array

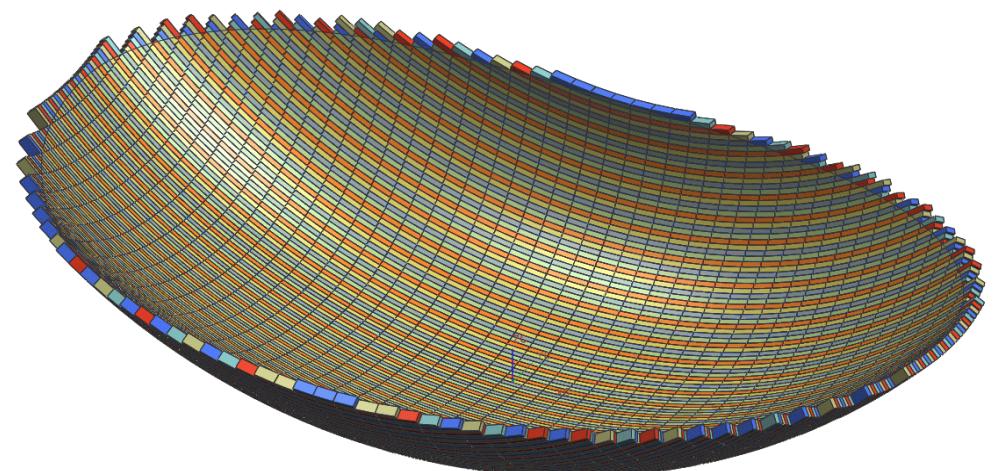
$$|\mathbf{B}| = B_{\text{rem}}(1 - e^{-kd})e^{-k\zeta} \quad (\text{if continuous rotation of } M)$$



Parameters:

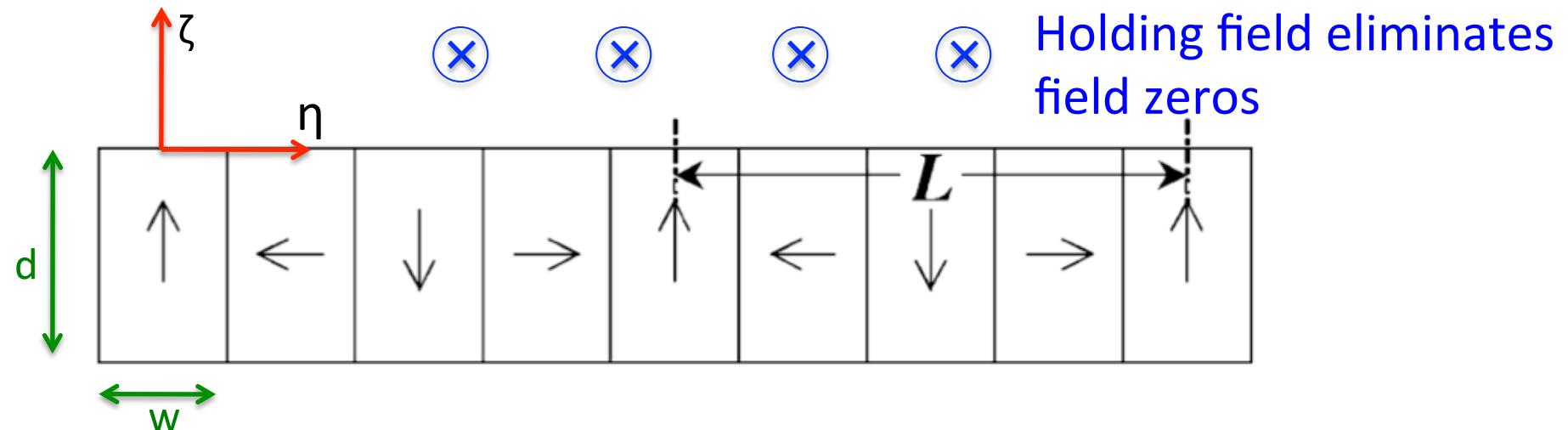
$$d = 2.54 \text{ cm}, w = 1.27 \text{ cm}, B_{\text{rem}} = 1.3 \text{ T}$$

→ min. trapping field 0.82 T at 2 mm,
corresponds to $mgh = |\mu_n B|$ with
 $h = 0.48 \text{ m}$



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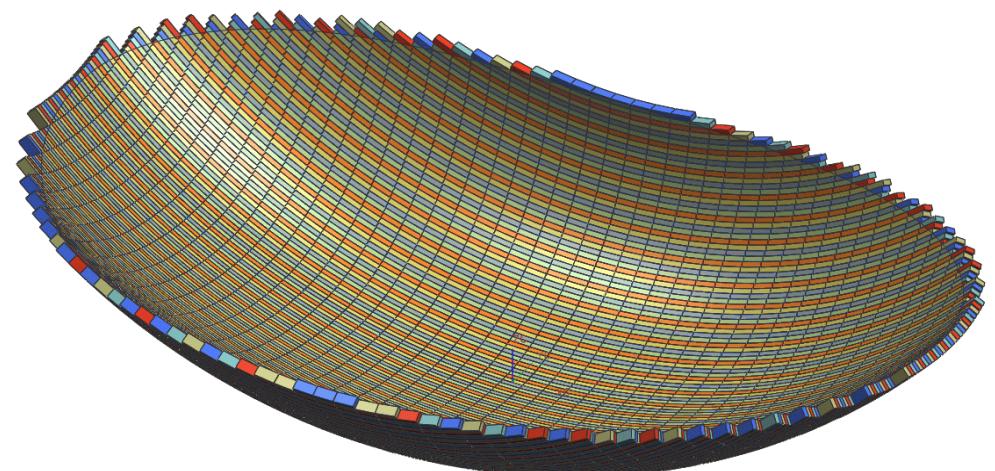
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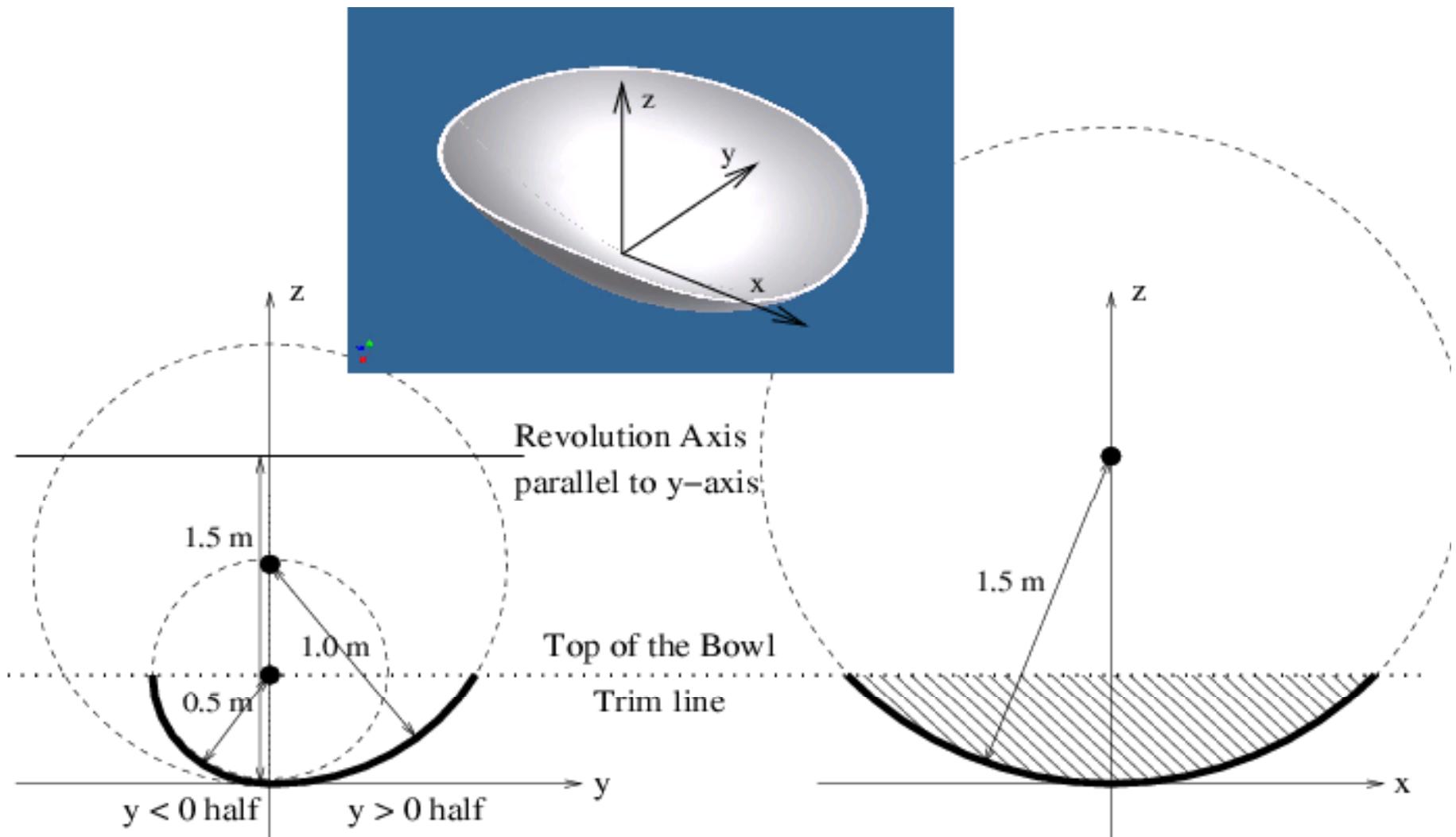
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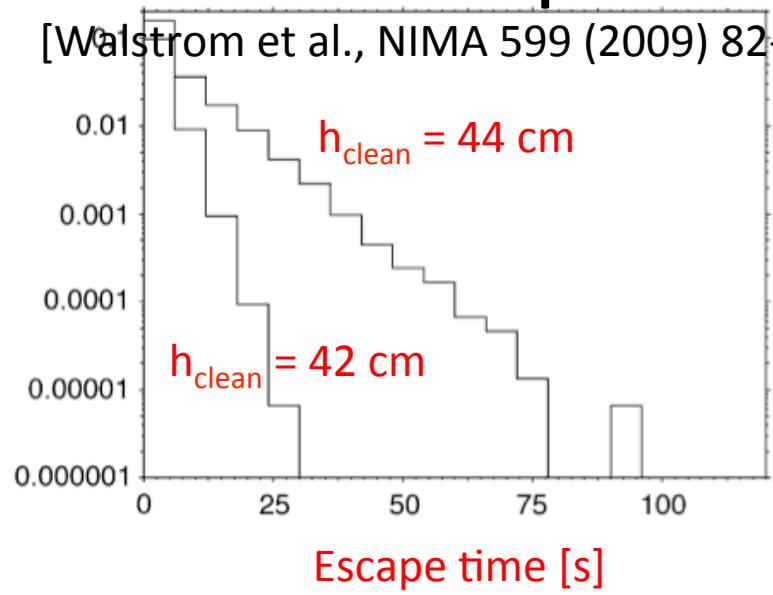
Removing quasi-bound UCN: Trap geometry



Removing quasi-bound UCN: Trap geometry

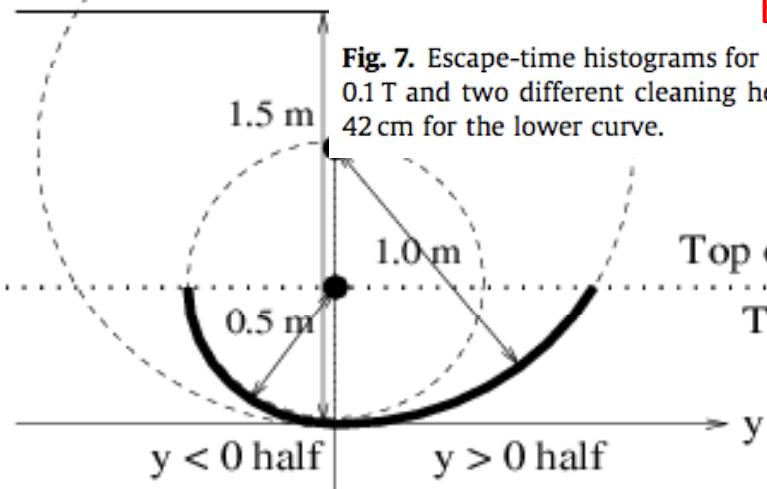
Simulation of trap cleaning

[Walstrom et al., NIMA 599 (2009) 82-92.]

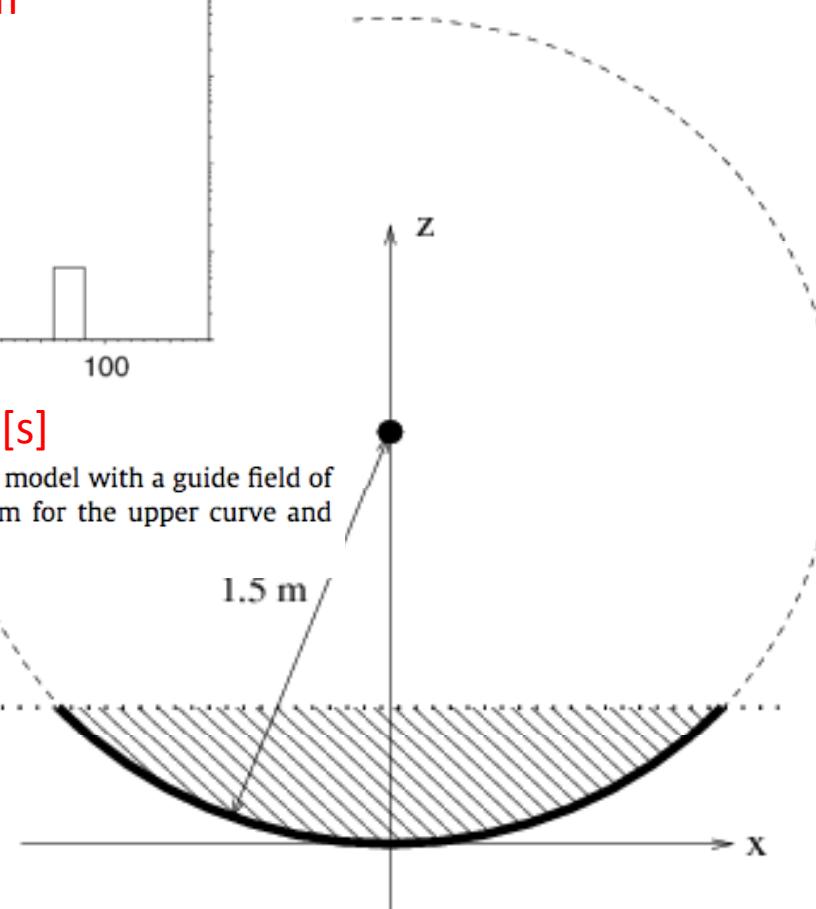


Escape time [s]

Fig. 7. Escape-time histograms for the two-way ripple model with a guide field of 0.1 T and two different cleaning heights: $h_{\text{clean}} = 44 \text{ cm}$ for the upper curve and 42 cm for the lower curve.

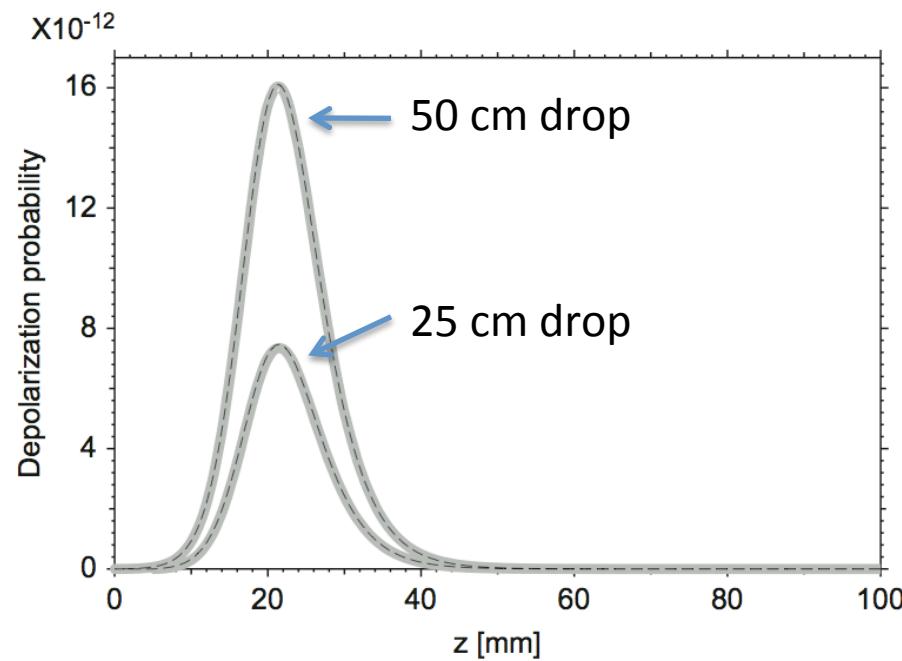


Top of the Bowl
Trim line



Losses due to depolarization

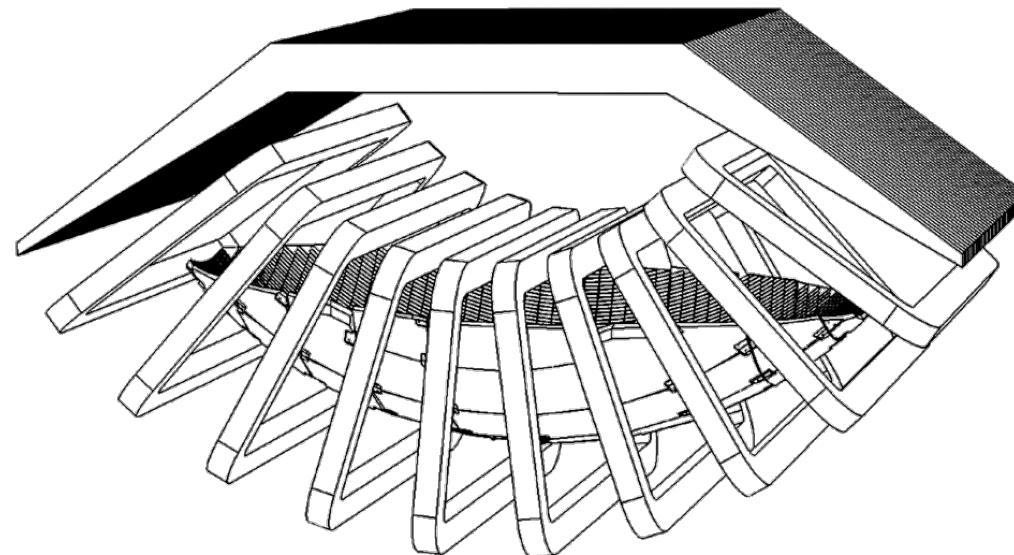
- calculated for “worst-case scenario”:
 - UCN dropped from 50 cm onto PM array
 - spin-flip loss per bounce $\sim 10^{-20}$ (negligible)



See also: A. Steyrl talk at SantaFe workshop,
or Steyrl et al., PHYSICAL REVIEW C 86, 065501 (2012)

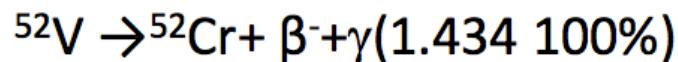
Design requirements

- No magnetic field zeros
- Filling mechanism
- Cleanout procedure for quasi-trapped neutrons
- No interaction with matter after cleaning
- Concept: P.L. Walstrom, J.D. Bowman, S.I. Penttila, C. Morris, A. Saunders, NIMA 599 (2009) 82-92



Magneto-gravitational trap with holding field

Vanadium activation¹ for *in situ* detection



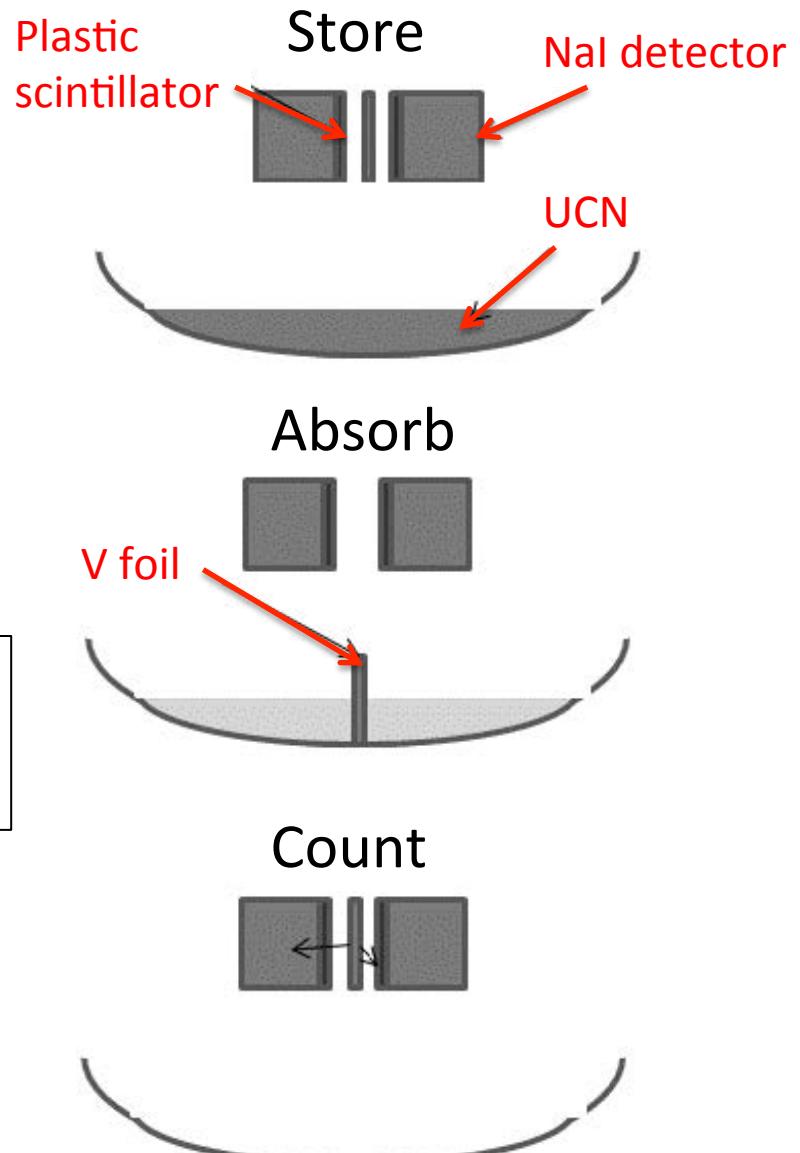
$\sigma = 5.08 \text{ b}$ @ 2000 m/s

$$\tau = \frac{1}{\rho \sigma v} = 1.24 \text{E-5 s}$$

$$mfp = v\tau = 0.0055 \text{ cm}@4.5 \text{ m/s}$$

See C. Morris, Proceedings from the 2012 Santa Fe workshop on Next Generation Experiments to Measure the Neutron Lifetime

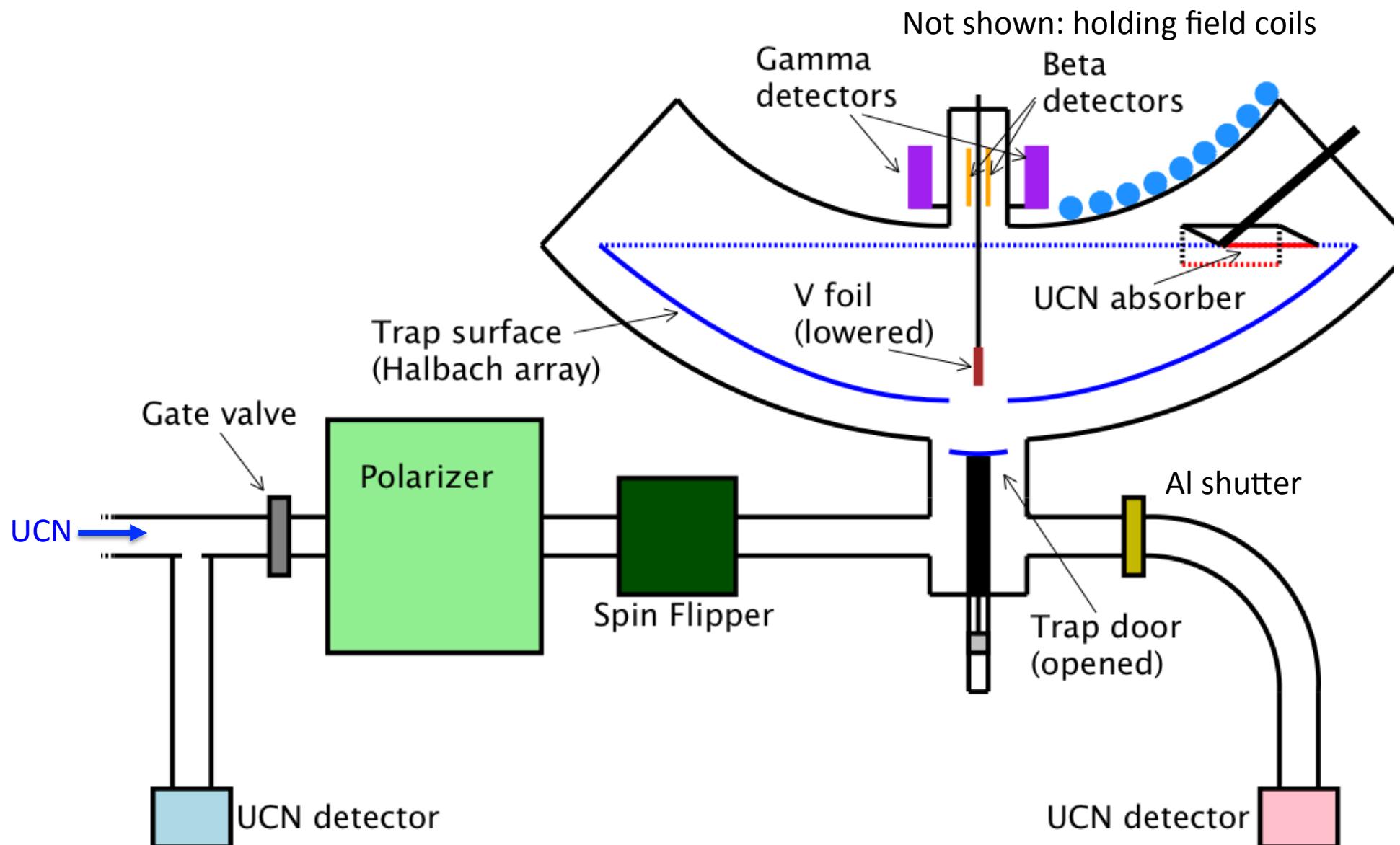
¹Frei, K. Schreckenbach, B. Franke, F.J. Hartmann, T. Huber, R. Picker, S. Paul, P. Geltenbort, "Transmission measurements of guides for ultra-cold neutrons using UCN capture activation analysis of vanadium", NIMA, 612, (2010) 349-353.



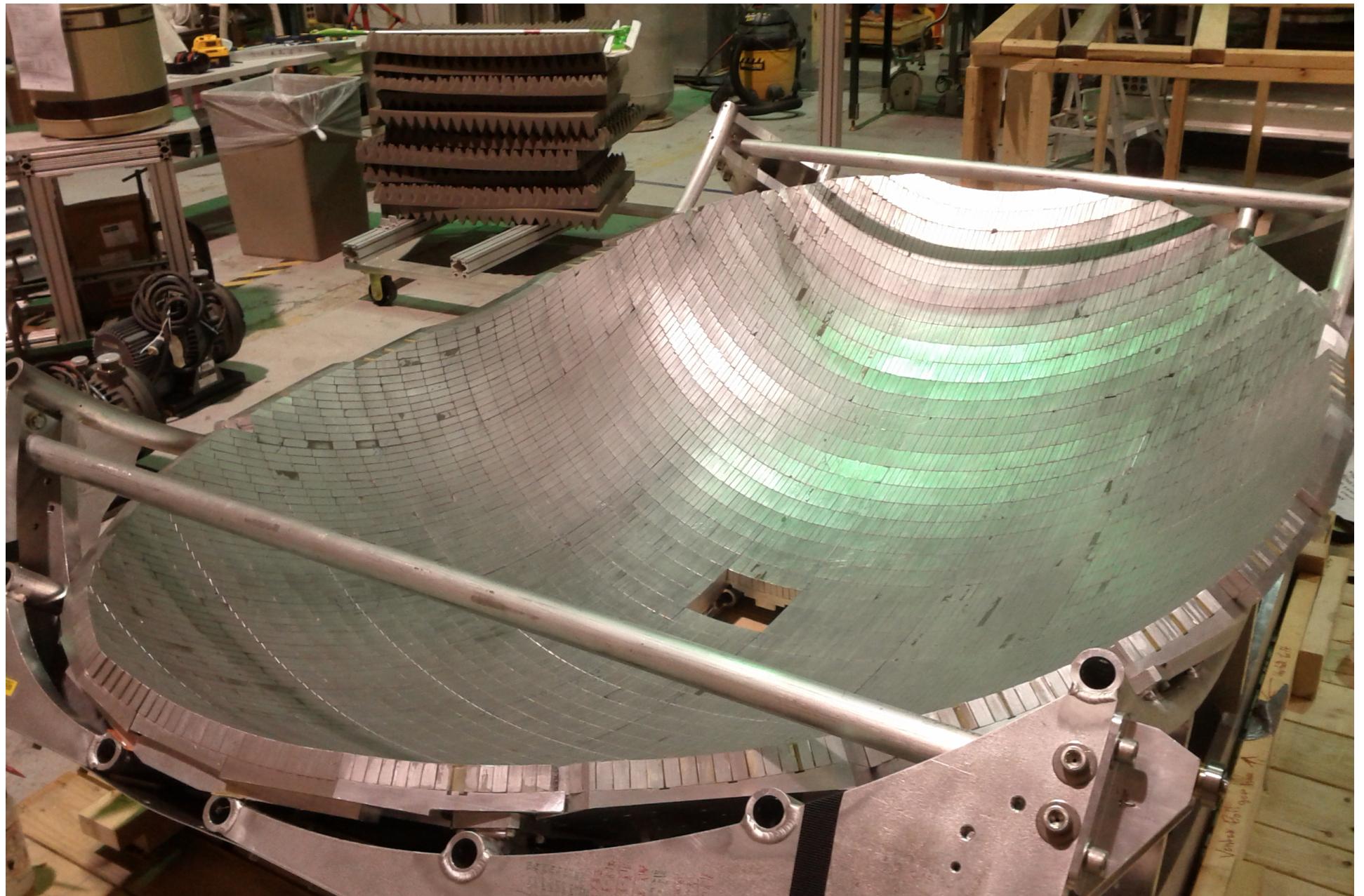
First measurements with prototype (Feb. 2013)

- Some V detector data (only 2 NaI detectors, no veto counters, not much passive shielding)
- Mostly took Fill-and-Empty data: UCN drained into a detector after various holding times.
- Holding field coils installed, but no flux return.

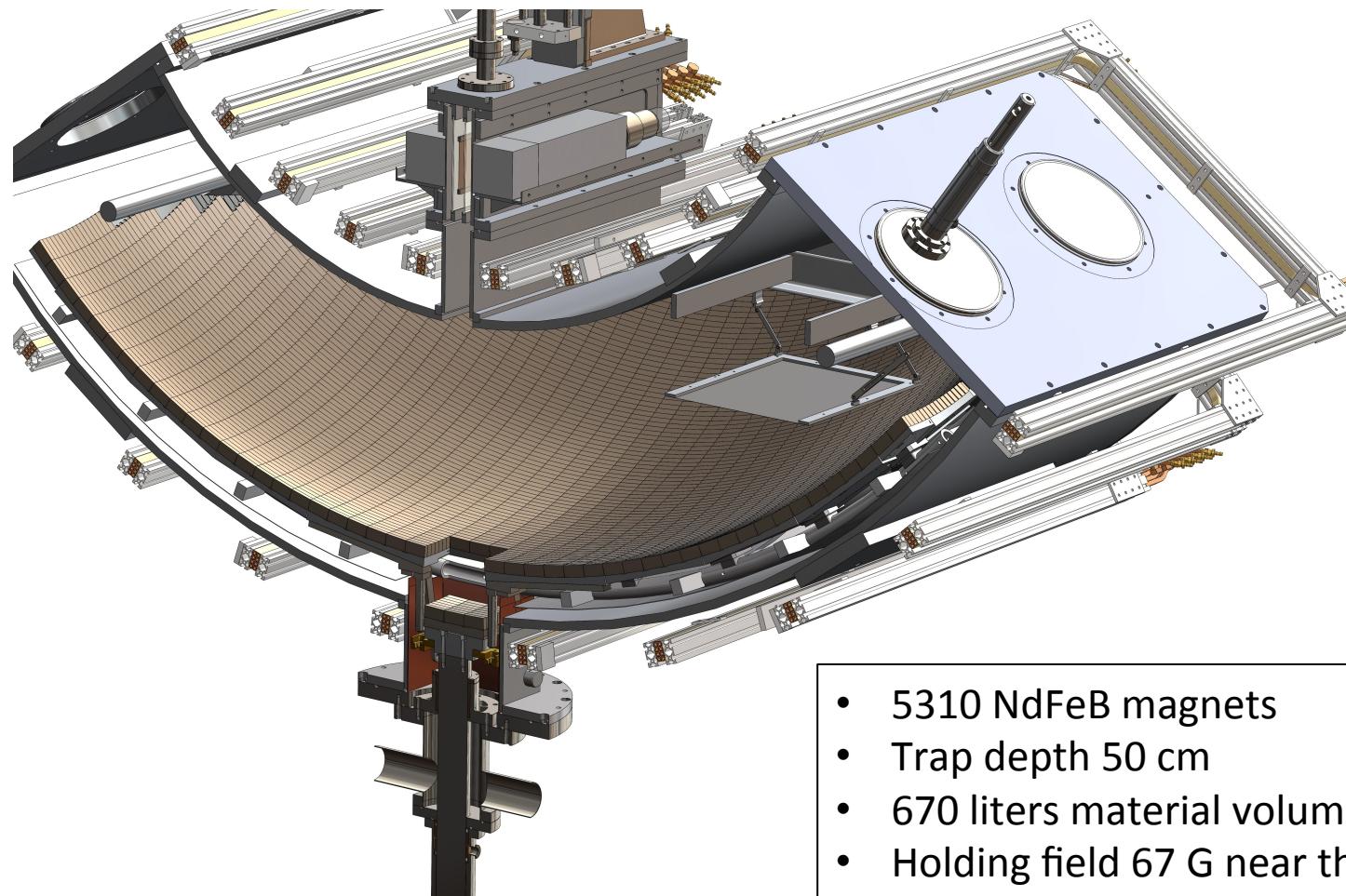
Test setup (Feb. 2013)



Completed Halbach array

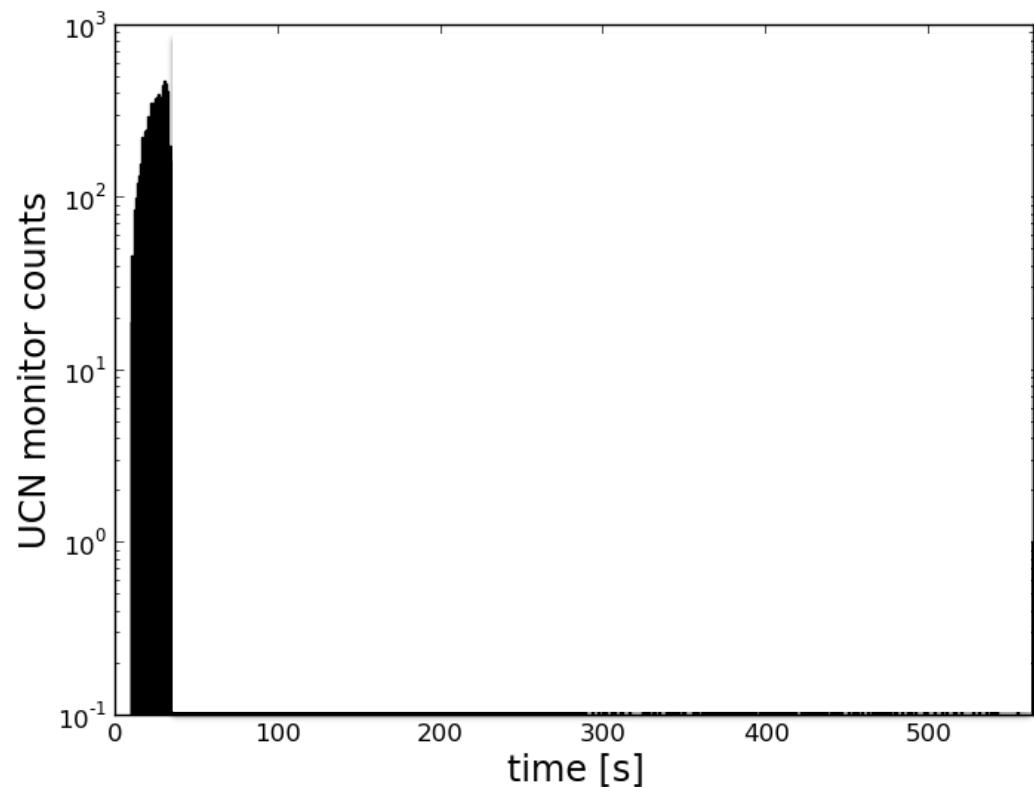
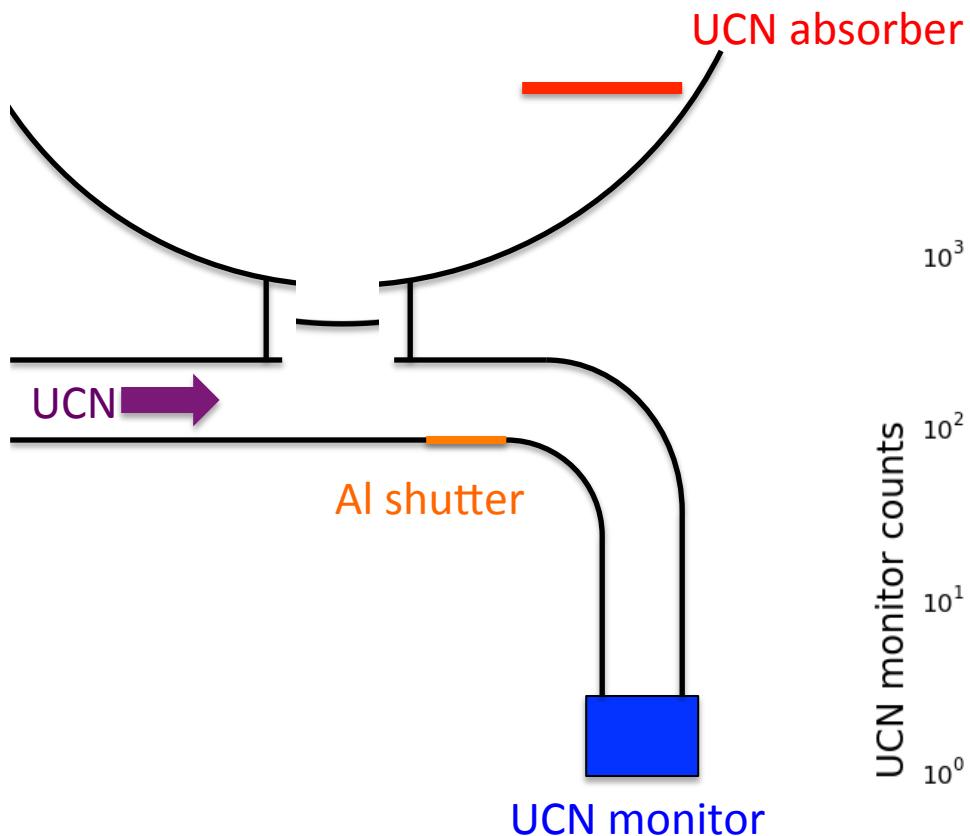


Prototype trap assembly (cutaway view)

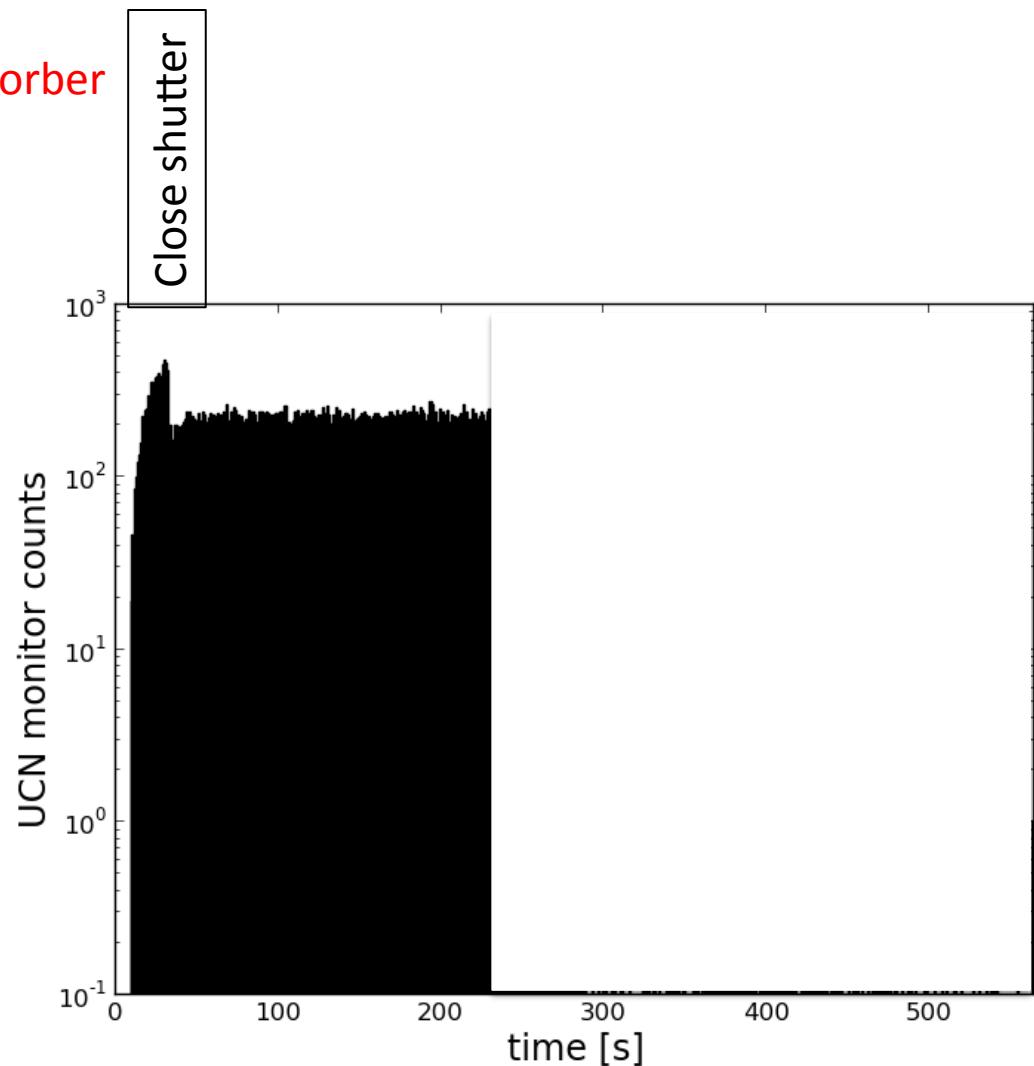
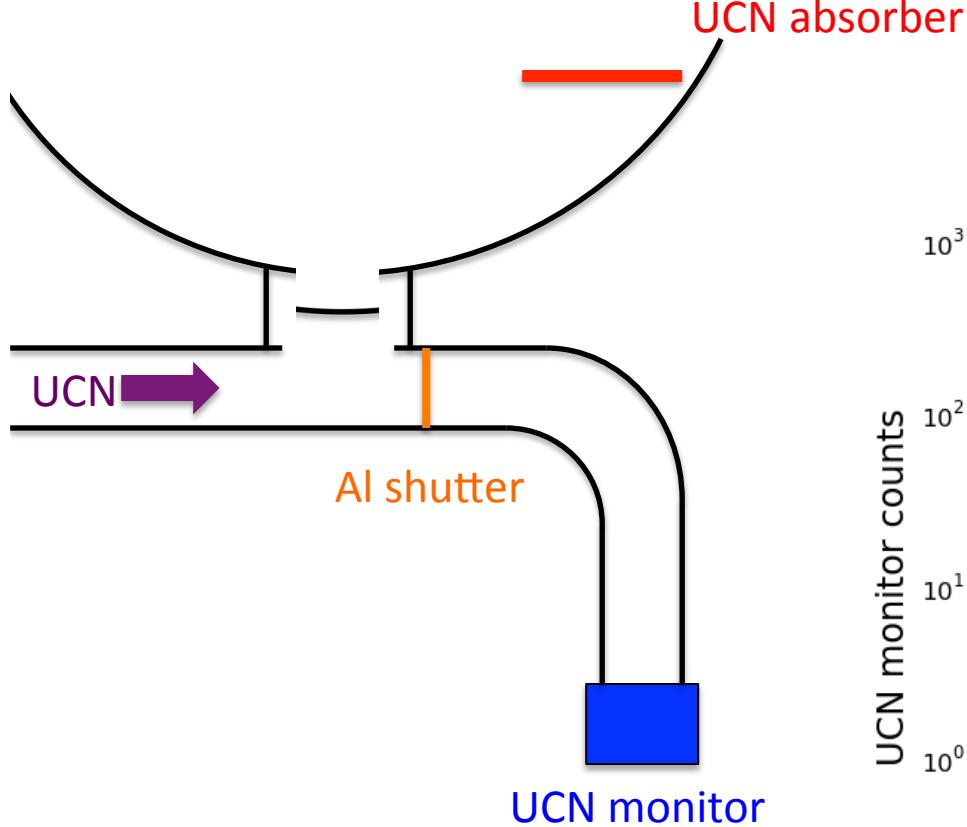


- 5310 NdFeB magnets
- Trap depth 50 cm
- 670 liters material volume
- Holding field 67 G near the bottom of the trap, 134 G near the top.

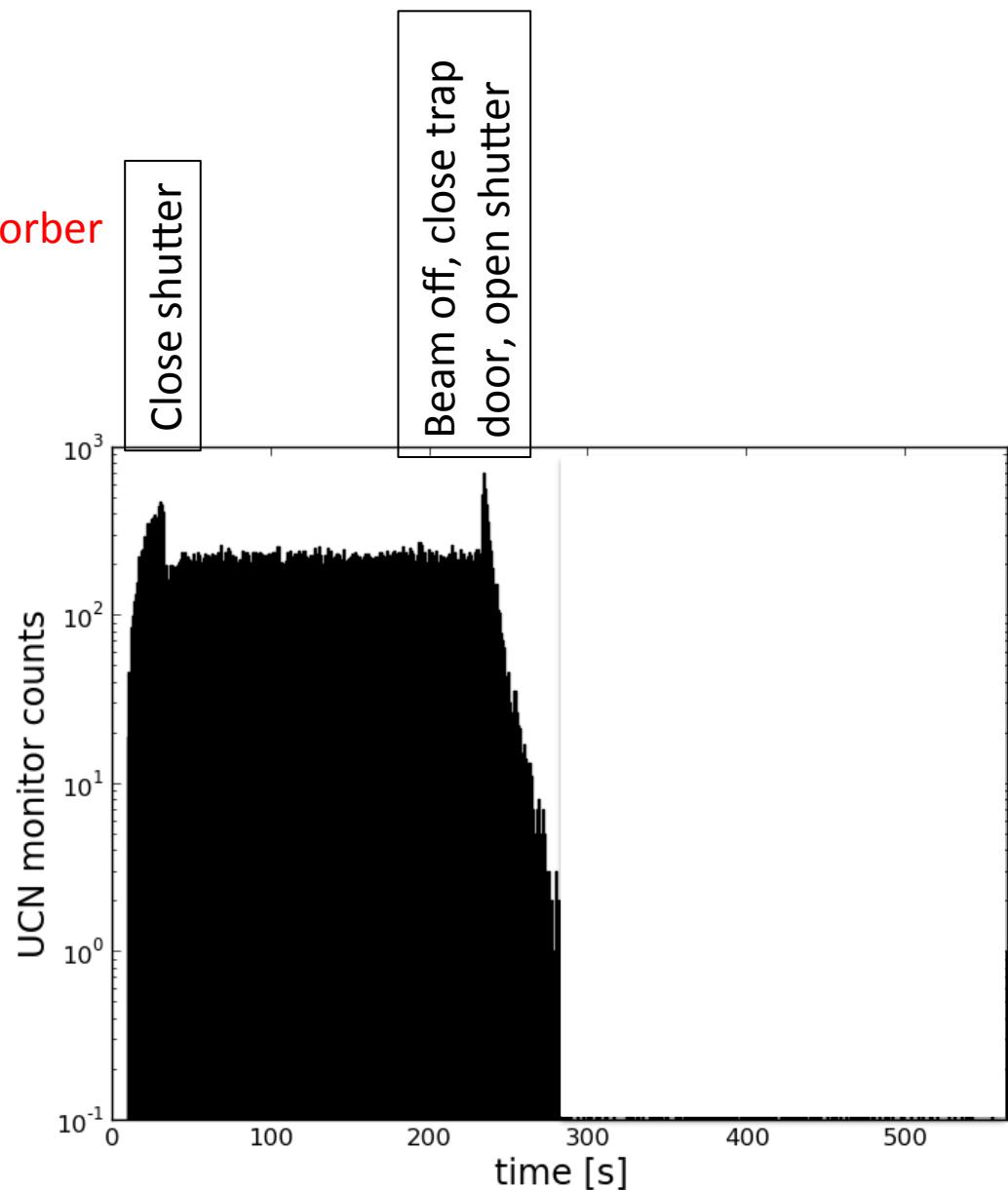
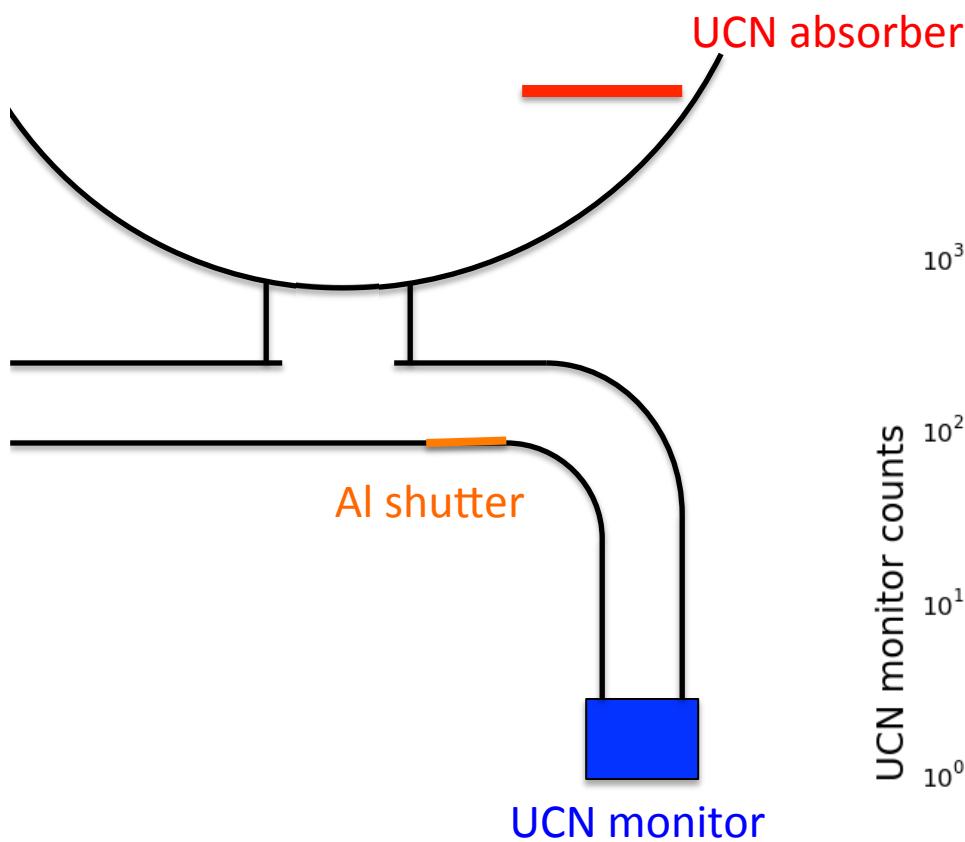
Fill-and-Empty Measurement



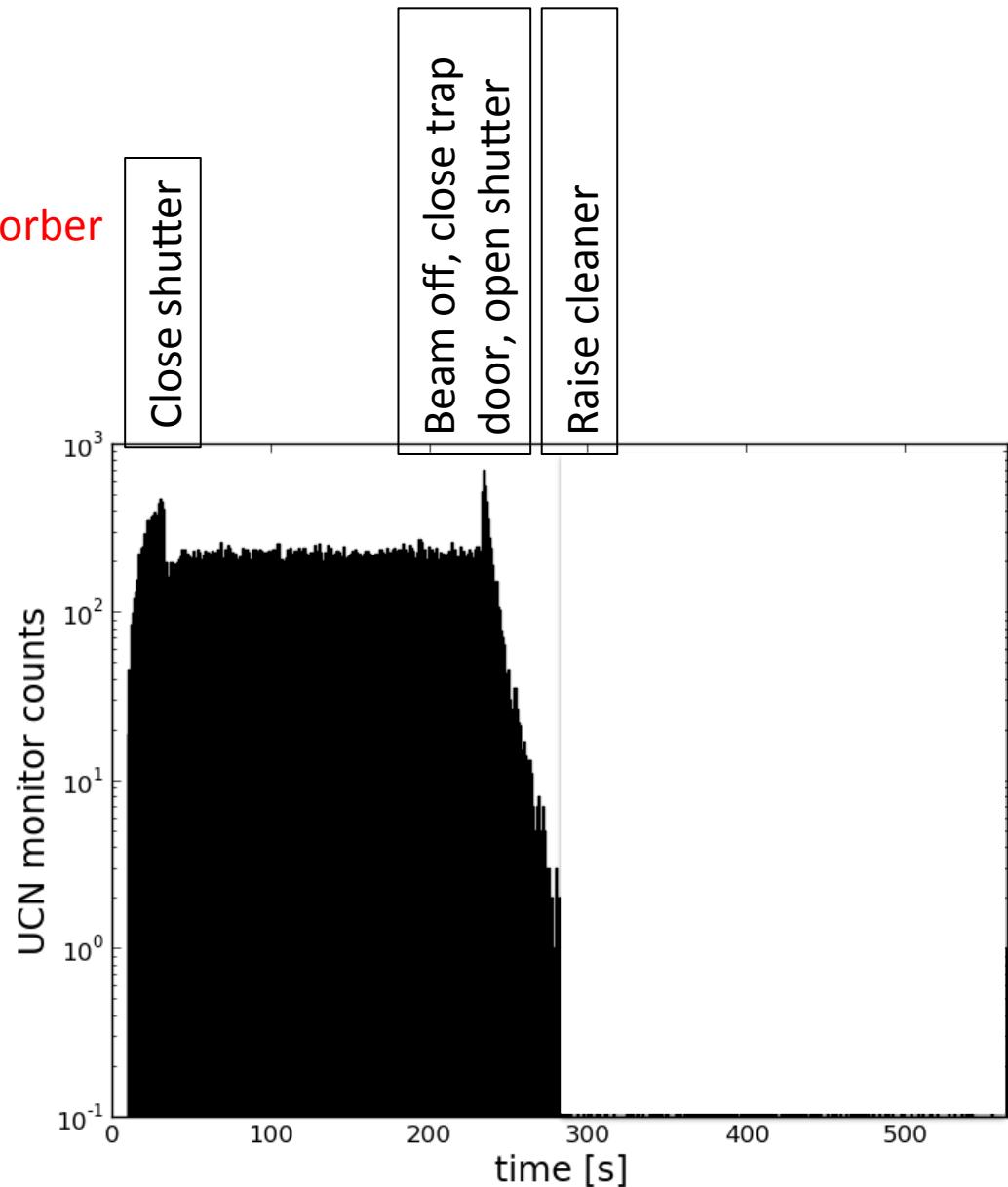
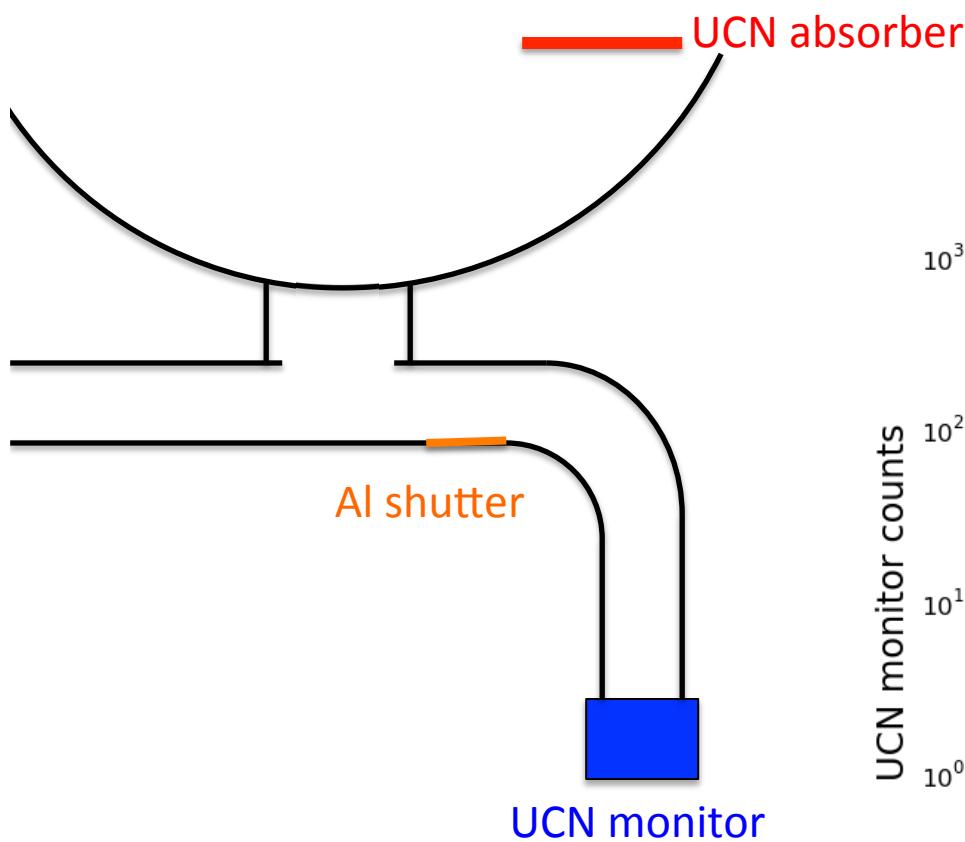
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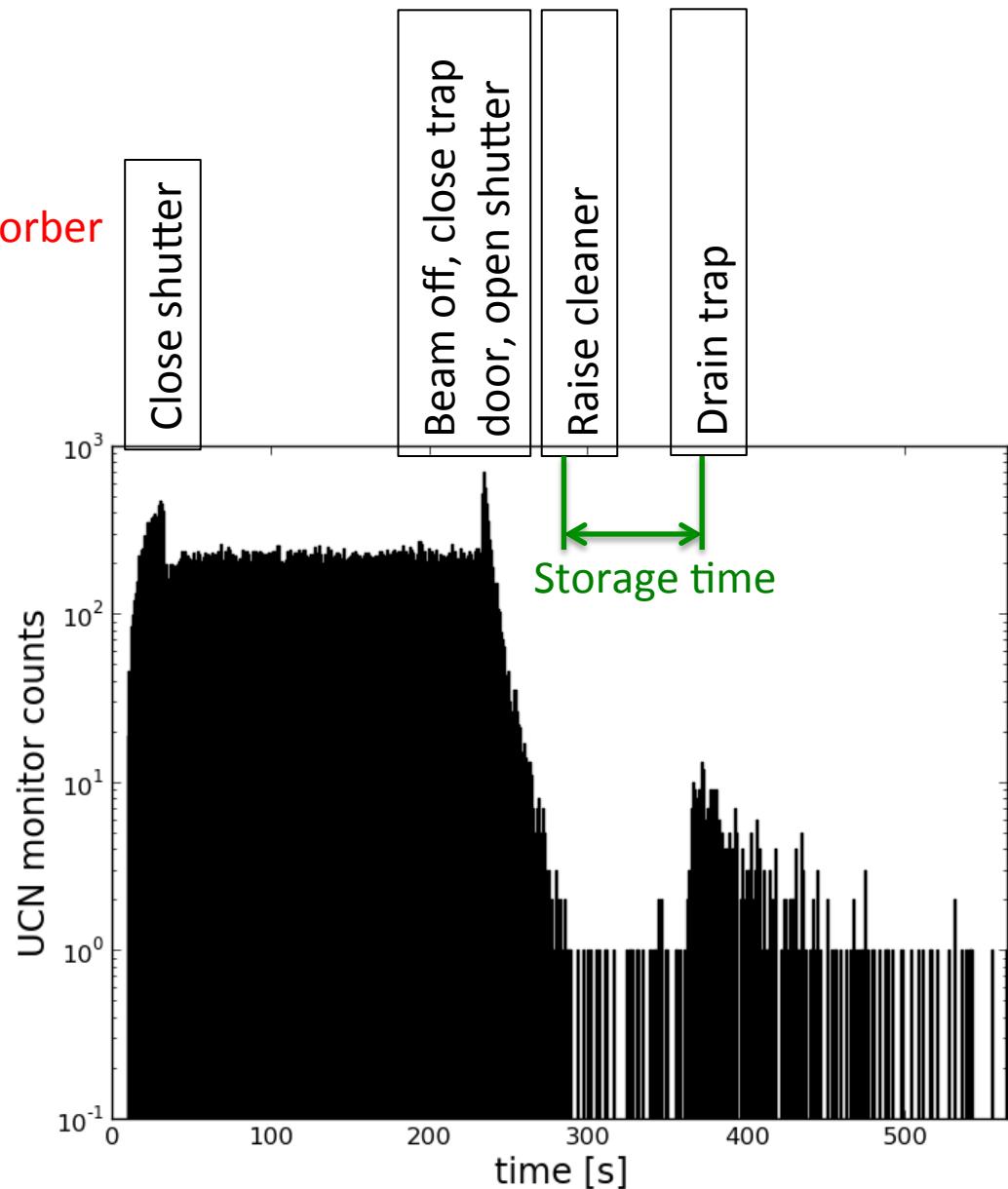
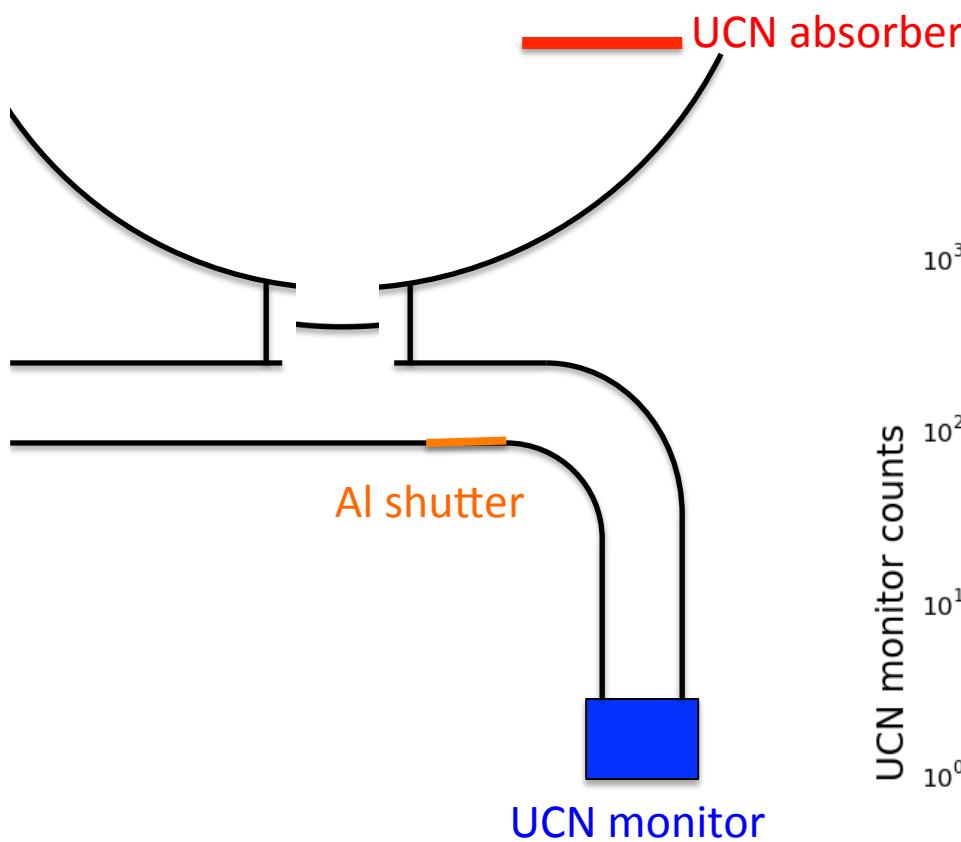
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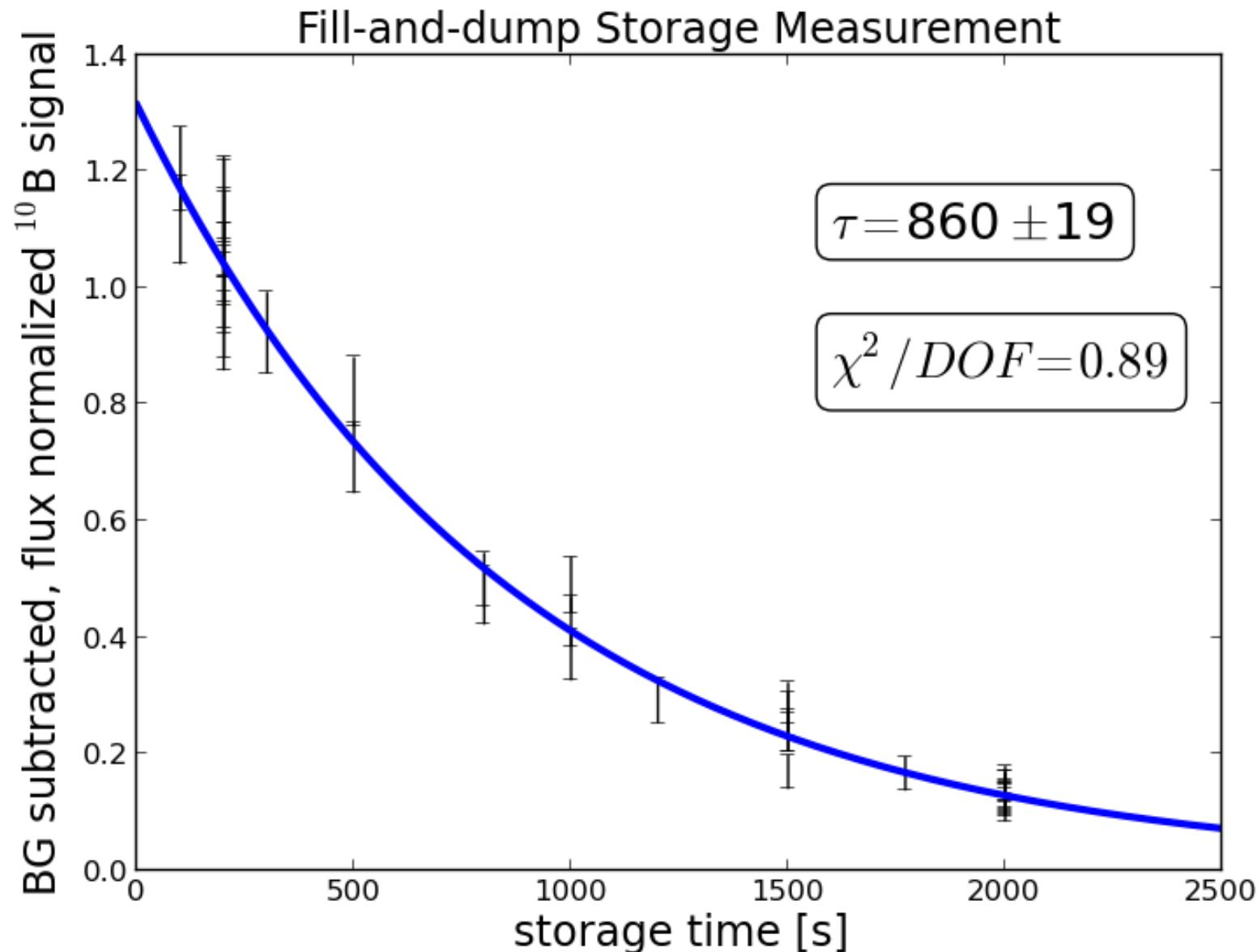
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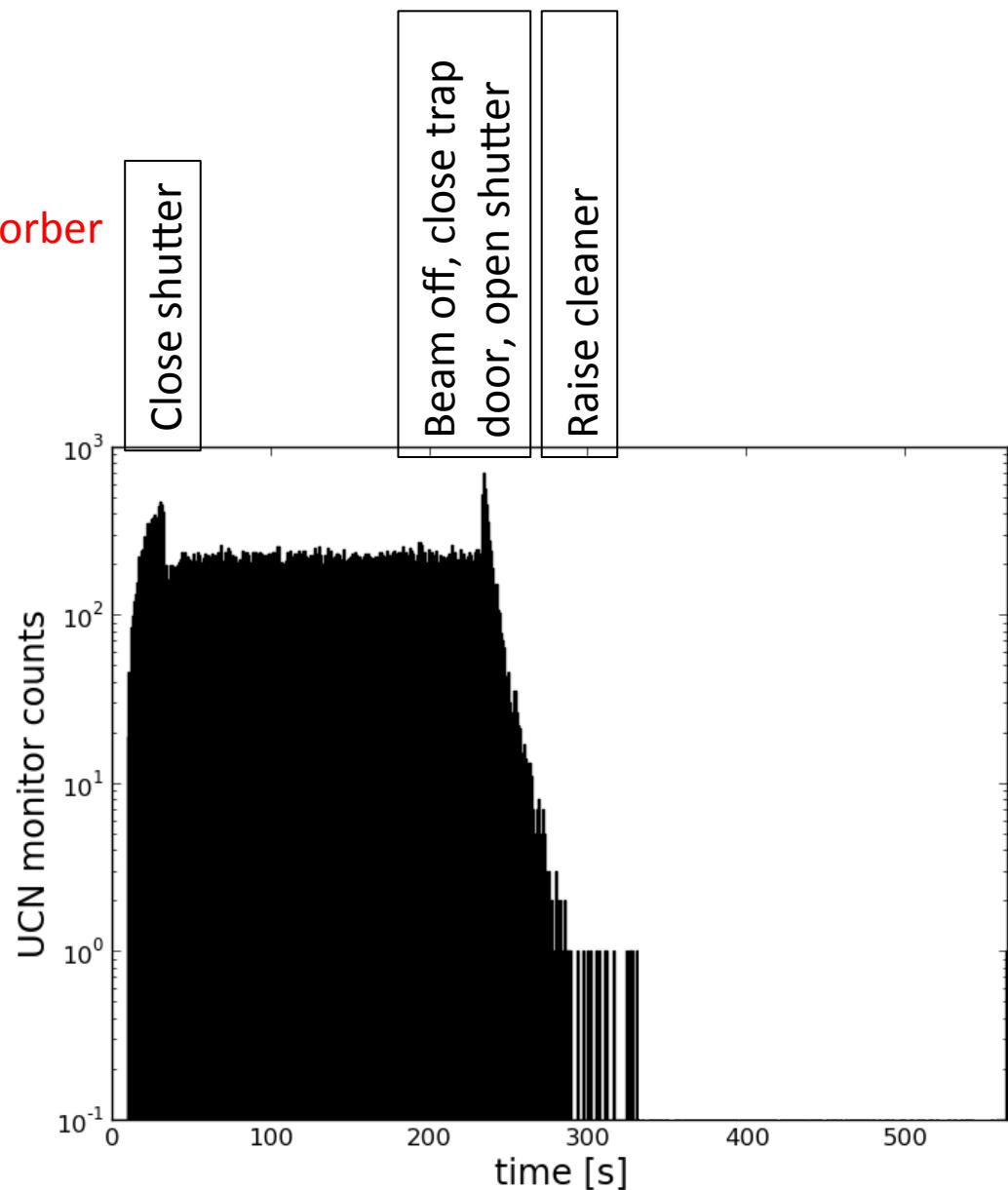
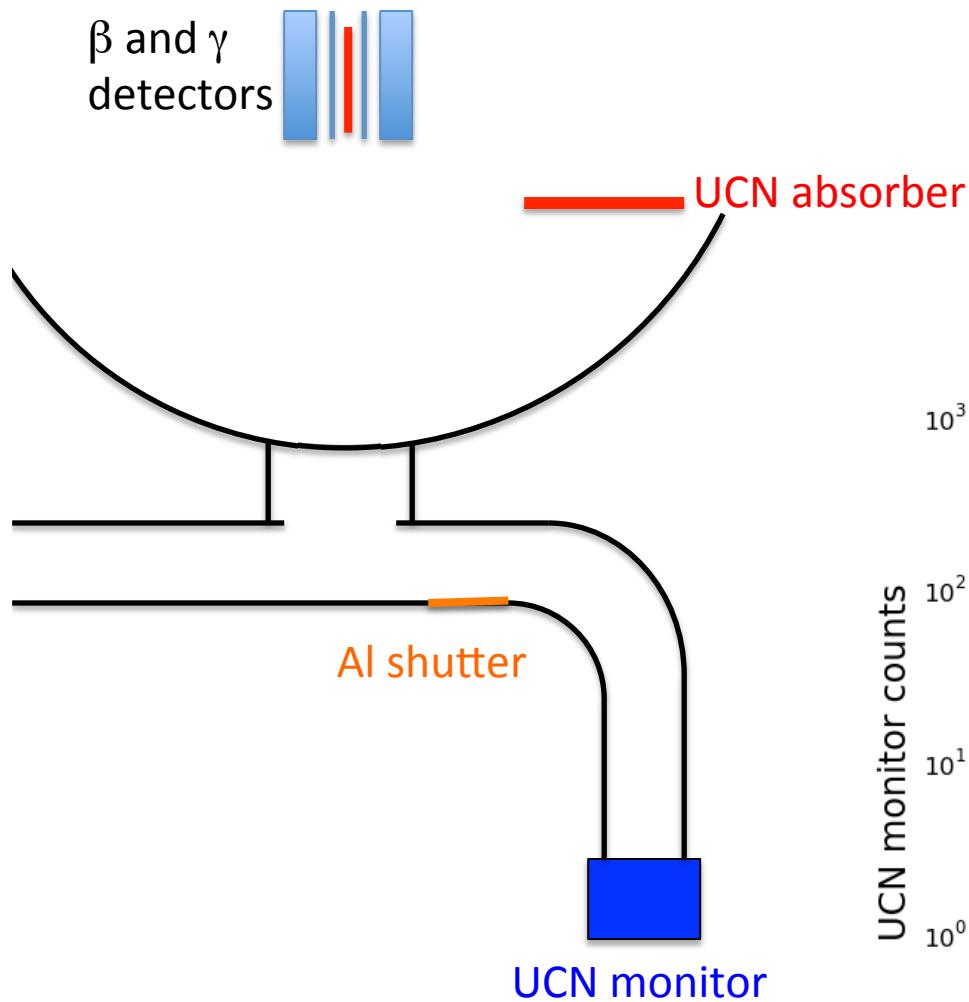
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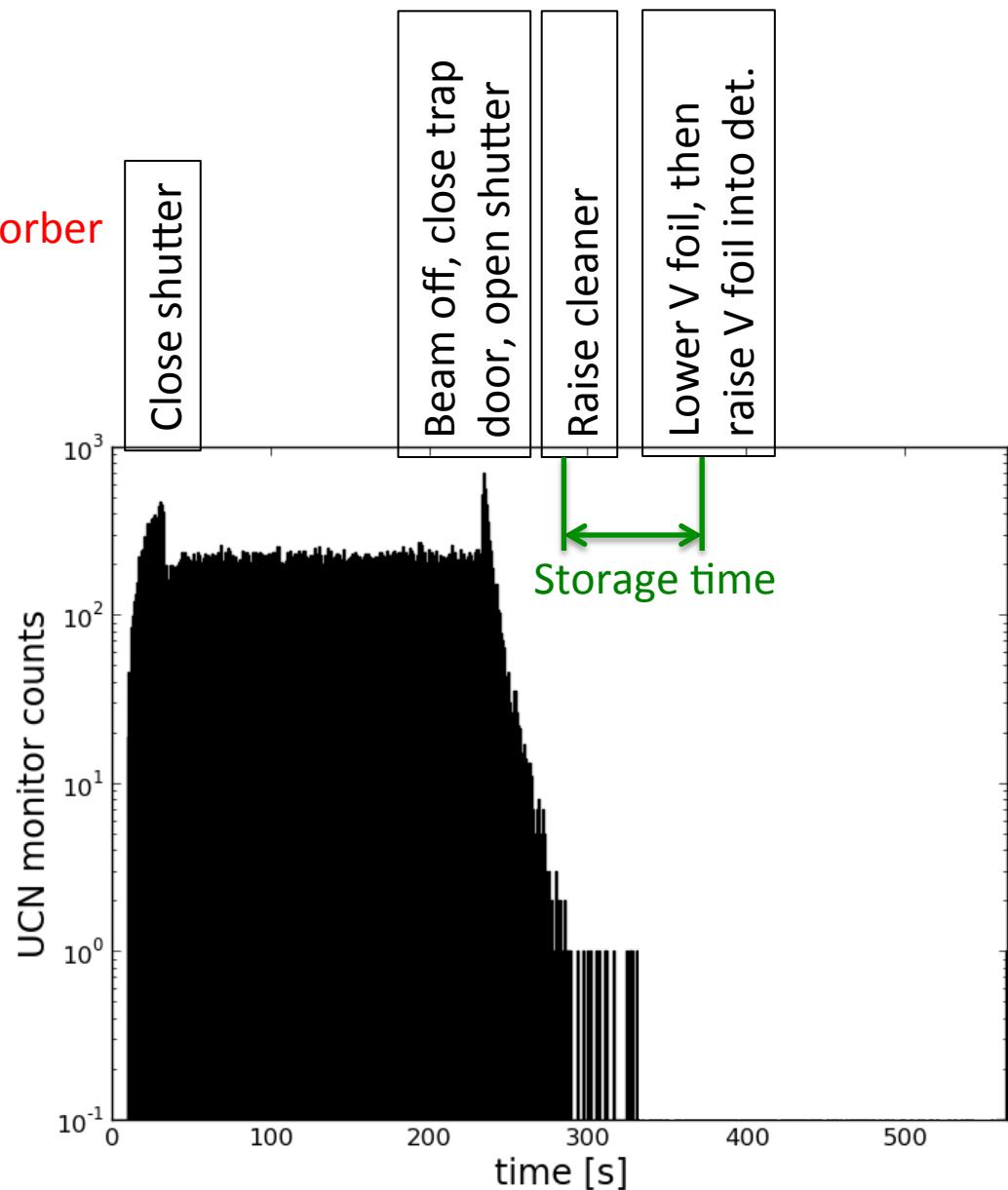
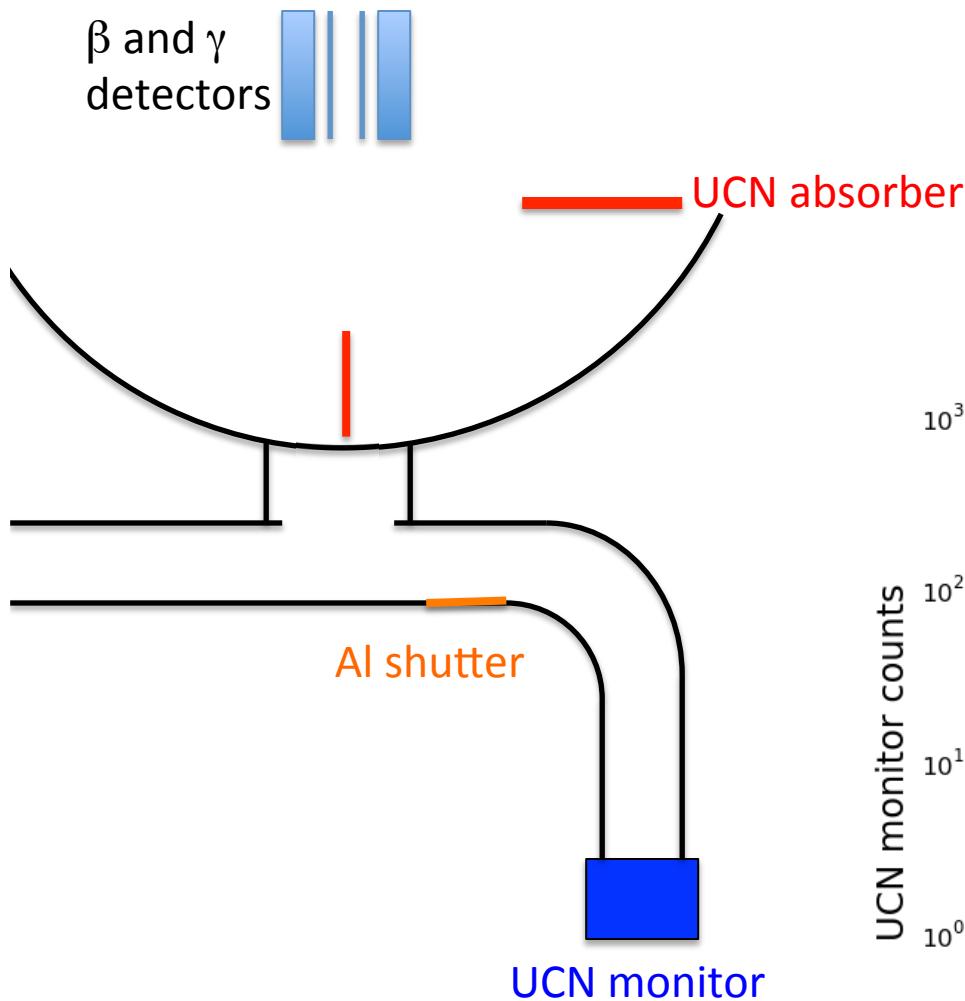
First storage time data (Feb. 2013)



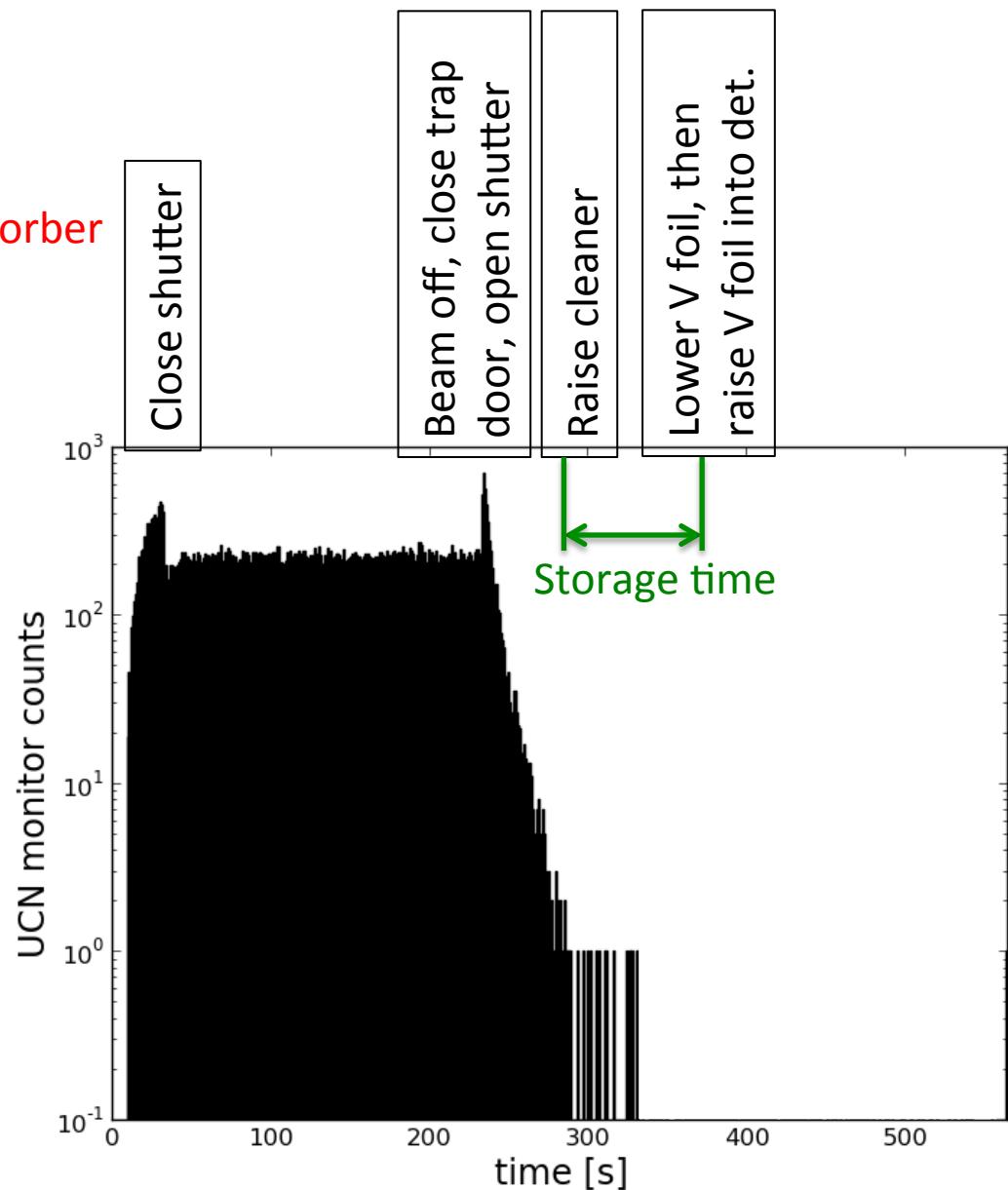
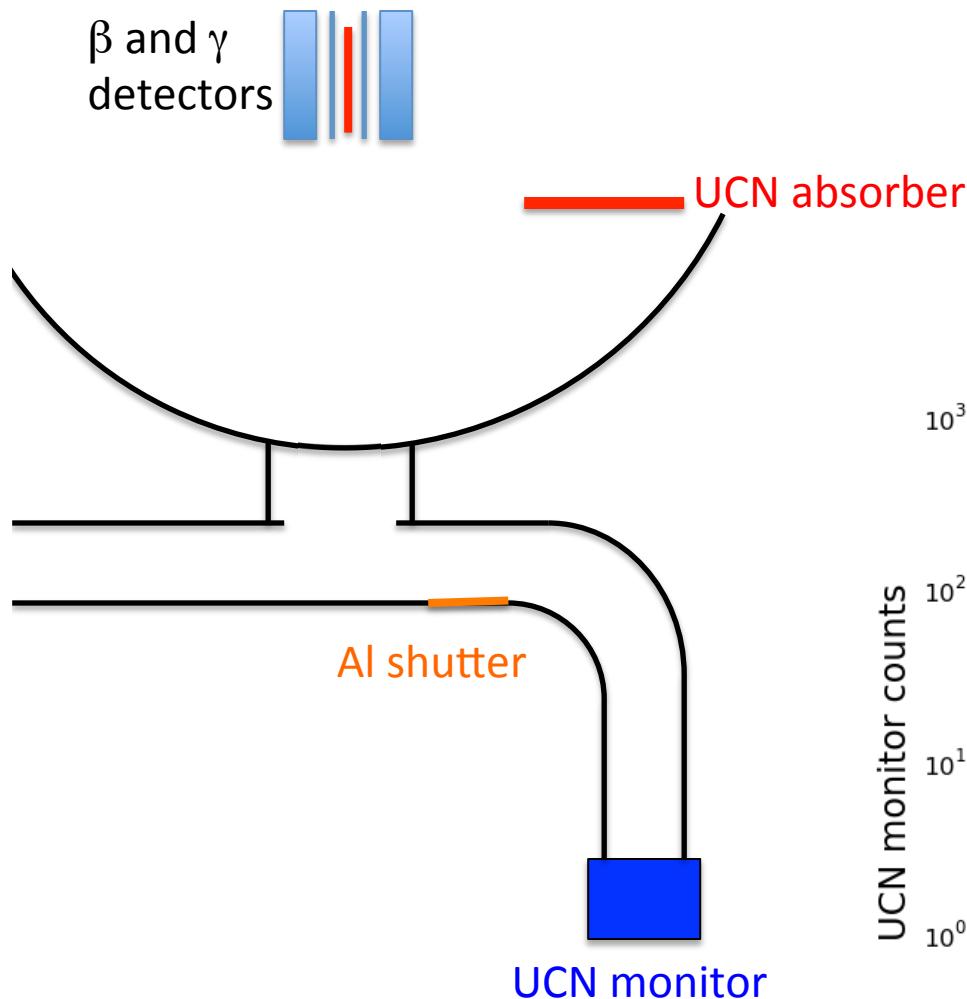
Fill-and-Detect Measurement



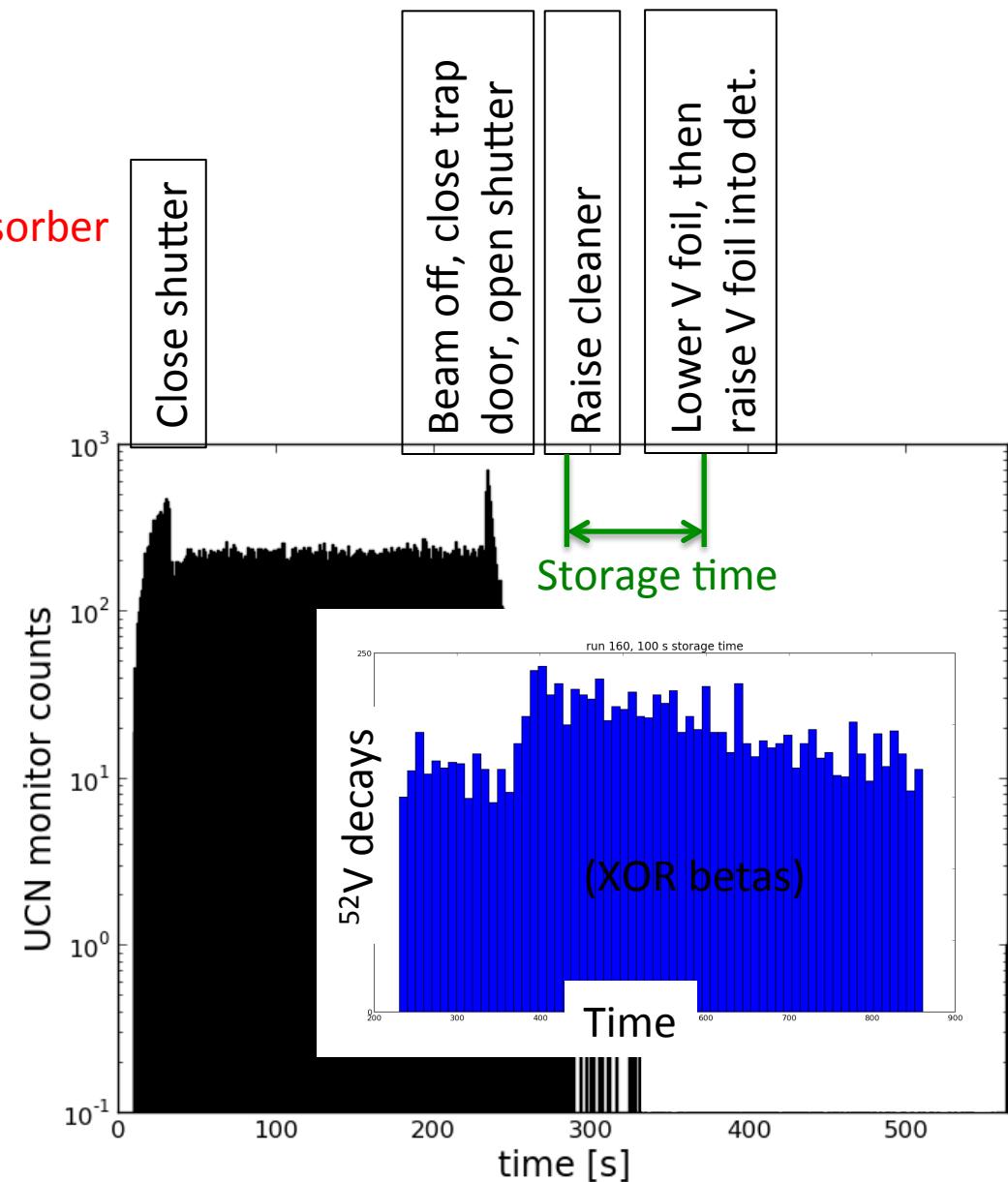
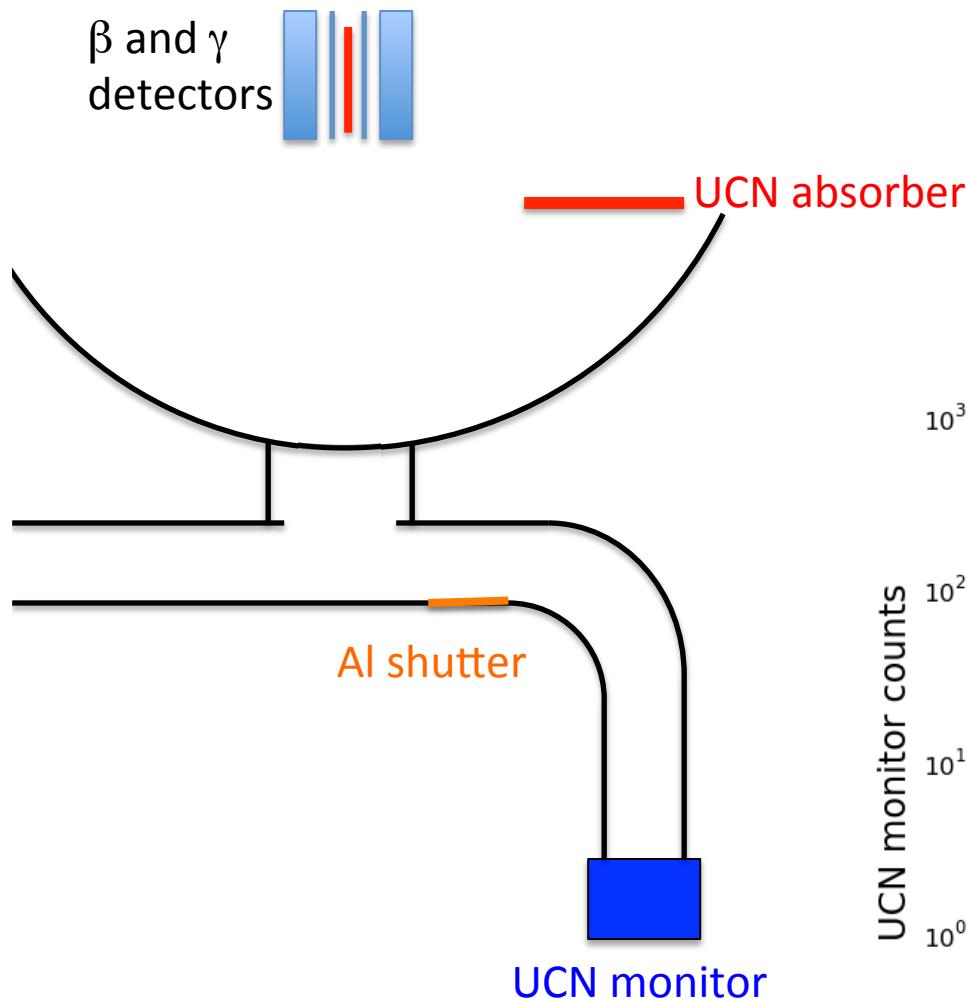
Fill-and-Detect Measurement



Fill-and-Detect Measurement



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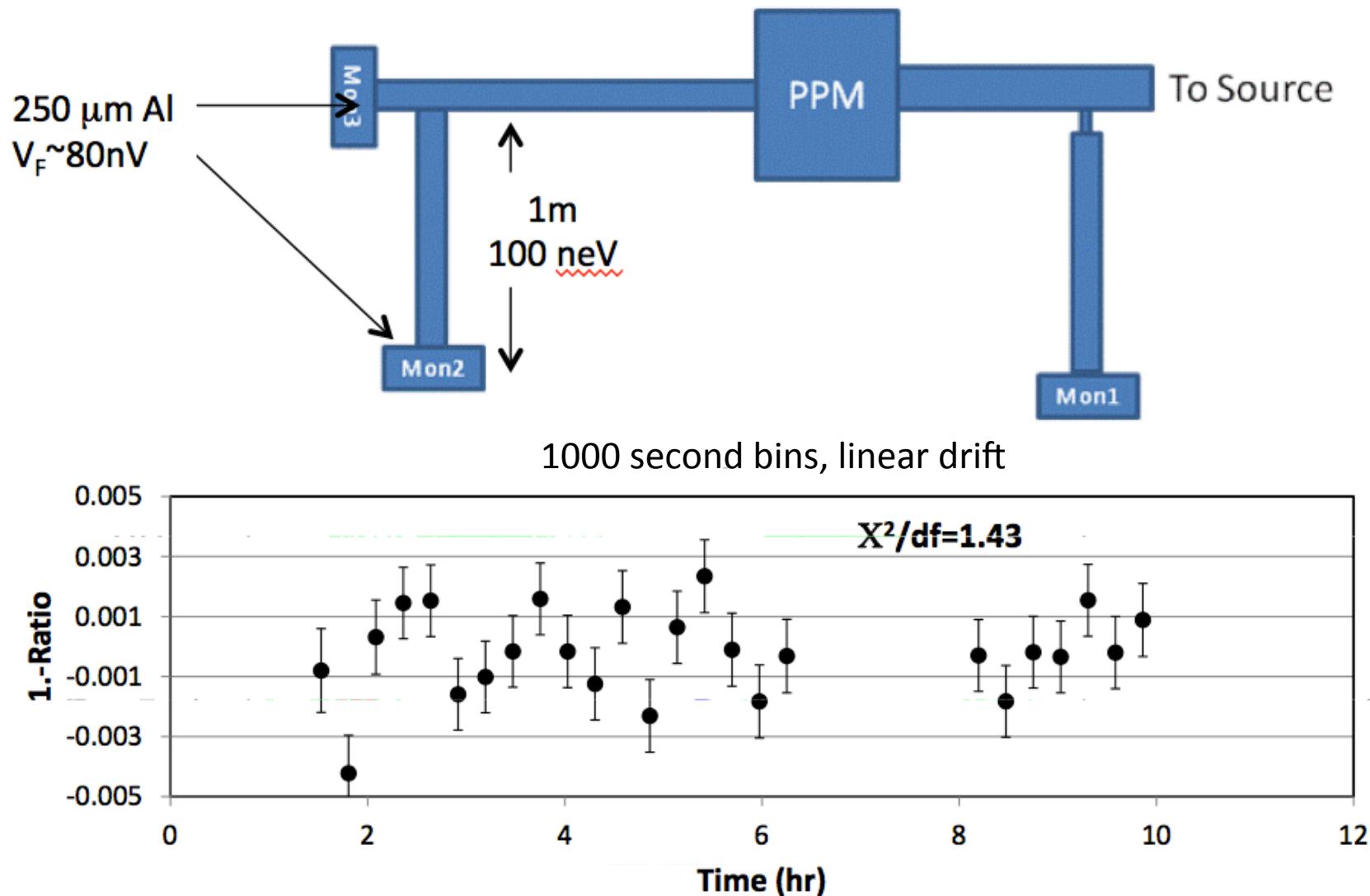


Conclusions

- First tests with UCN in prototype asymmetric magneto-gravitational trap show a long storage time.
- The prototype will be used to study systematics and evaluate the feasibility of a sub-1 second measurement.
- Next steps include the following:
 - Complete V detector; improve shielding
 - Improve trap loading efficiency
 - Improve magnetics (flux return for holding field)
 - Map B-field on trap surface (fix chips?)
 - Take more data with UCN

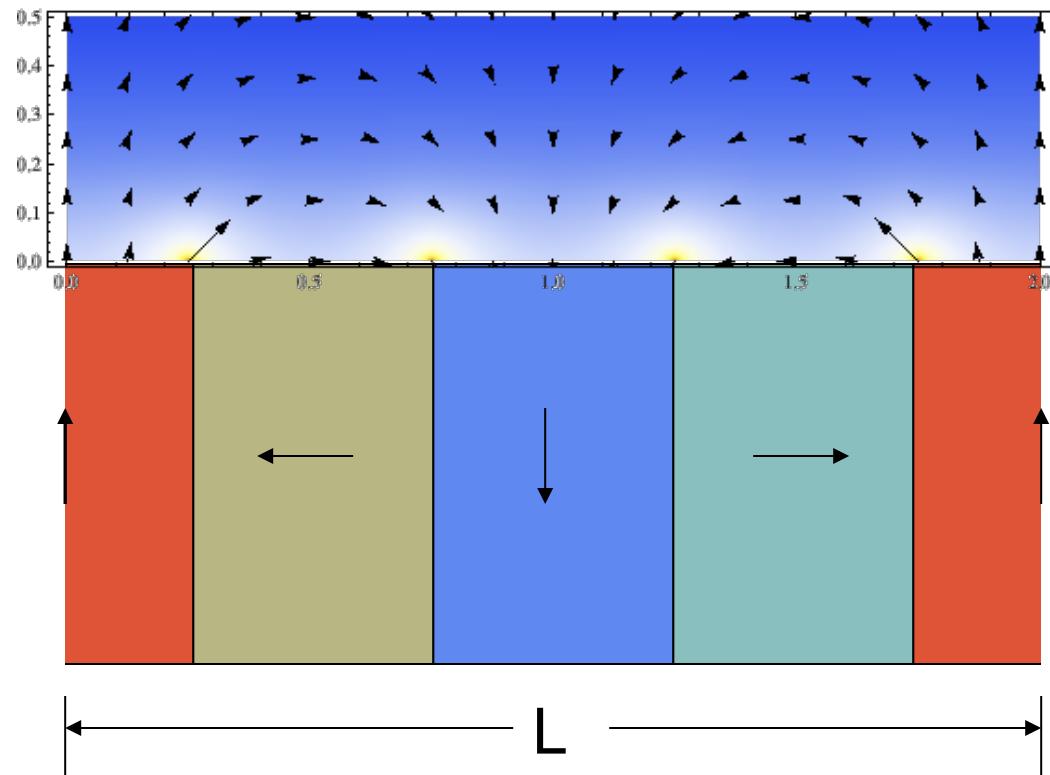
Extra Slides

Trap normalization: test of beam stability

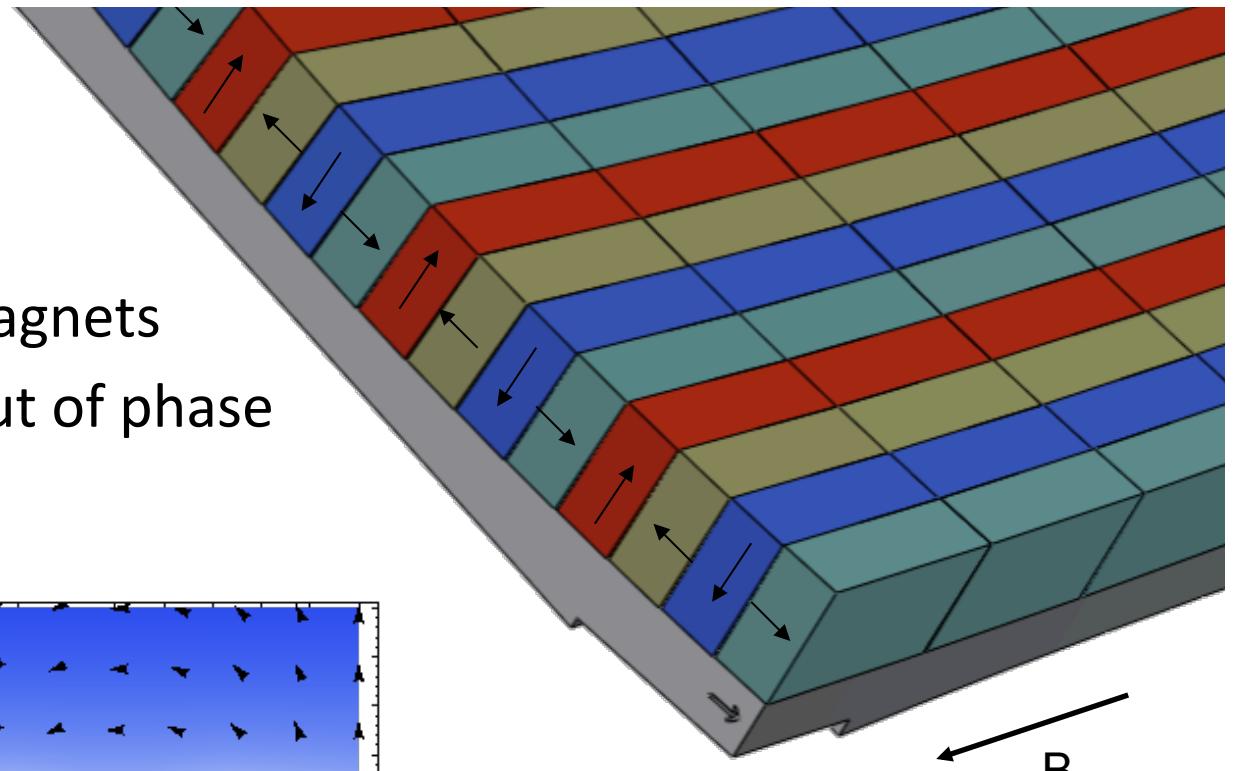


Halbach array

- 1.2 T permanent magnets
- Each magnet 90° out of phase with its neighbor.



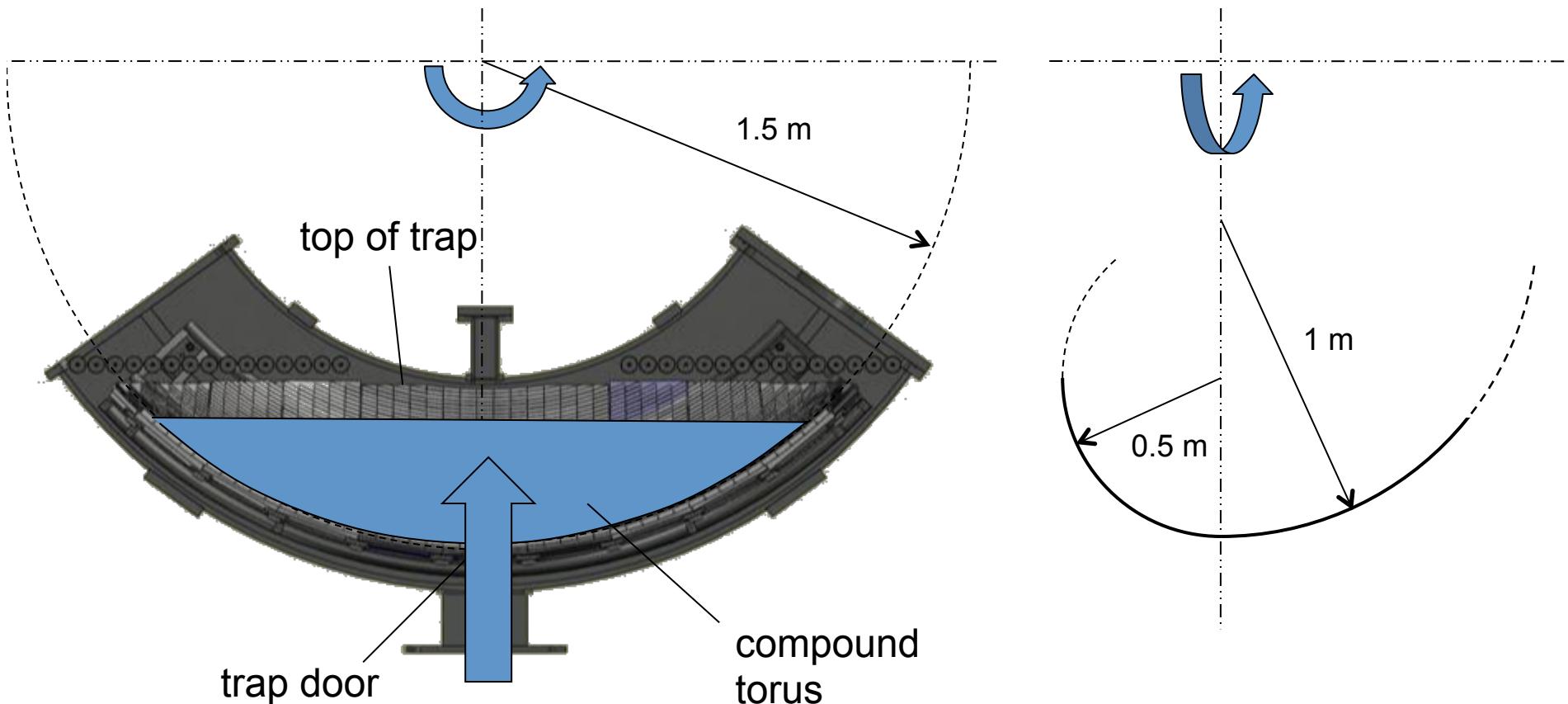
Kevin Hickerson



- The array has B field “ripples” of scale $L/4 = 0.5$ in
- Rotating field is orthogonal to holding field B_0

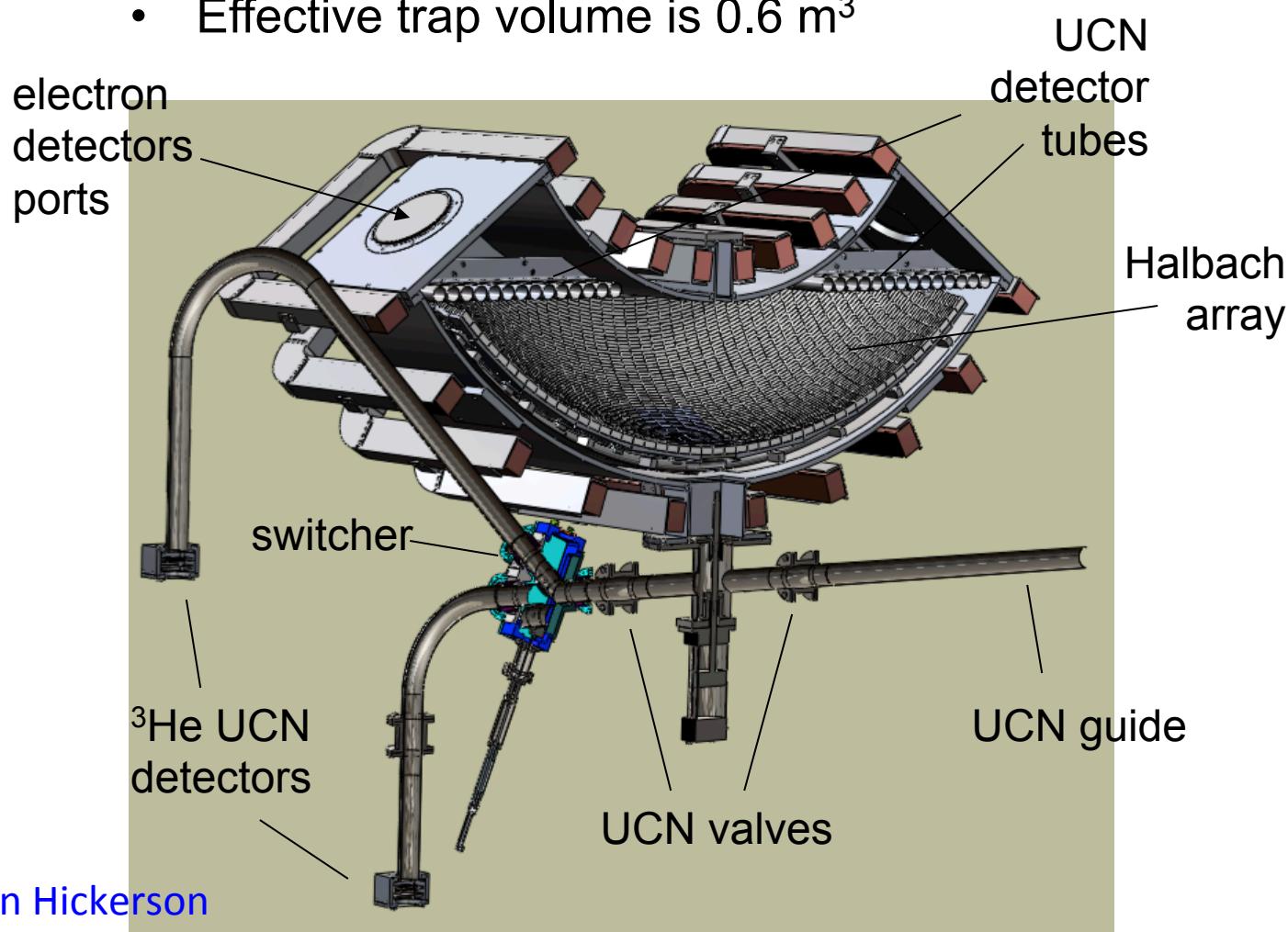
Overview of Experiment

- Asymmetric compound toroidal trap fills trap phase space
- UCN trapped by gravity in open-top bowl (“the bathtub”)
- UCN fed in from trap door below



Overview of Experiment

- Permanent magnets repel UCN on bottom
- Minimize material interactions
- Effective trap volume is 0.6 m^3



Draining time

- Do some UCN “circle the drain”?
- Not addressed in Walstrom et al. (orig. scheme was to detect betas)
- Only highest energy UCN see chaotic-orbit-inducing field ripple
- Possible solutions?
 - active absorber
 - more simulation

